Corrosion Control of Steel Reinforcement Rods in Concrete

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Courtesy: Some images are sourced from the internet for demonstration purposes only.

OUTLINE OF PRESENTATION

- Need for Durable Reinforced Concrete Structures
- Mechanism, Causes and Consequences of Corrosion of Steel in Concrete.
- Corrosion Prevention Methods : Surface Coatings – Corrosion Inhibitors - Coatings to Steel Rebars – Cathodic Protection
- Summary

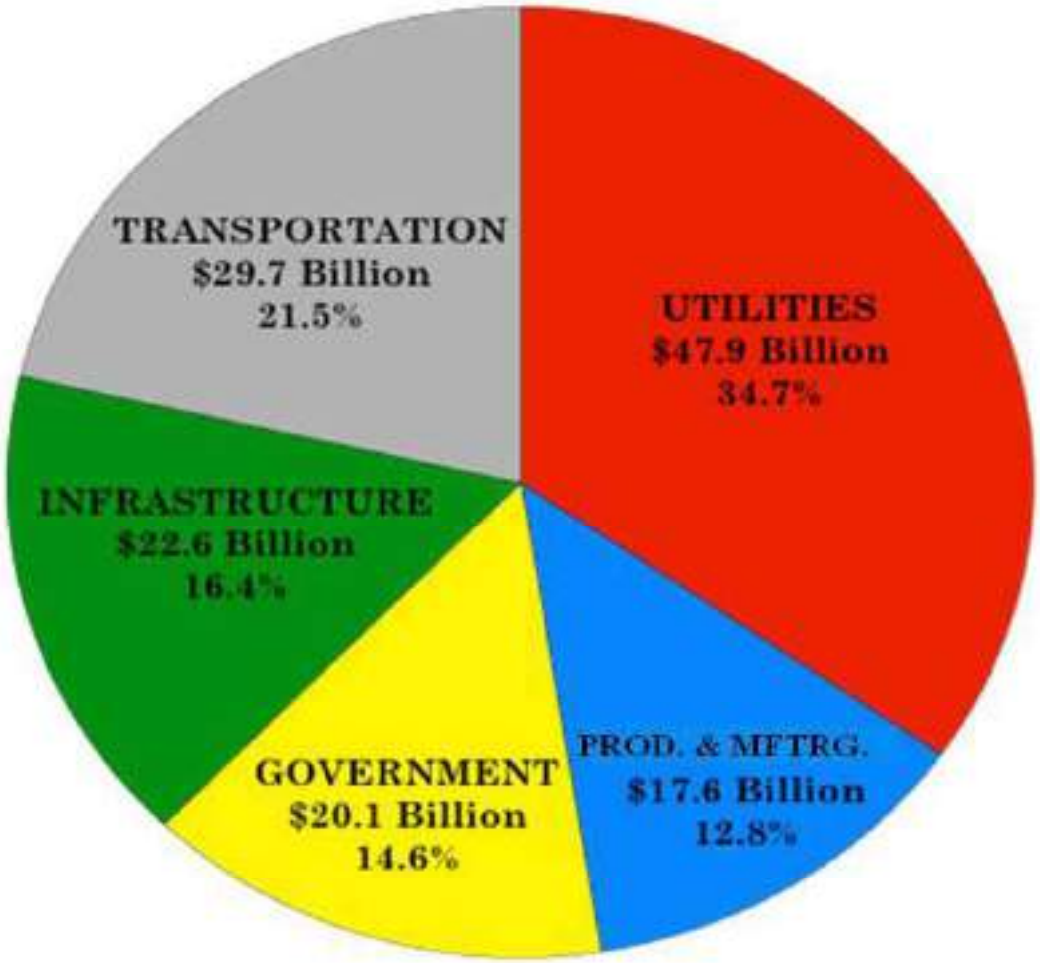
INTRODUCTION

- Concrete is a construction material that is relatively easy to work with.
- The low tensile strength of concrete necessitates reinforcing steel bars in regions of tension.
- The combination of concrete and steel - inexpensive and durable material widely used in the construction.
- The concrete deterioration in marine structures, chemical manufacturing plants and bridges (1960's)

INTRODUCTION

- Recognized the cause as corrosion of reinforcing steel in the mid 70's - due to intrusion of chloride into the concrete.
- Based on FHWA (1997) report, 20% of the bridges in and around U.S. are rated as structurally deficient.
- Annual loss due to direct and indirect corrosion in U.S. is around 6% of G.D.P.
- In U.K. around 50% of the annual construction industry's expenditure is spent on repair and rehabilitation.
- The annual loss due to corrosion in India is more than Rs.2,00,000 crores. (2013)

Cost of corrosion



Corrosion cost split-up in the USA (FHWA 1998)

- > Rs. 2 lakhs crores/year
- ~ 4% of GDP
- ~ up to 50% construction budget
- 50% structures hit a repair in about 10 years
- 40% steel
- 30% cement

A corrosion protection strategy to minimize the repair and maintenance costs is a MUST

FHWA 1998, George Hays 2004

INFRASTRUCTURE DEVELOPMENT IN INDIA

- Roadways
- Railways
- Ports
- Airports
- Urban
- Rural
- Industrial

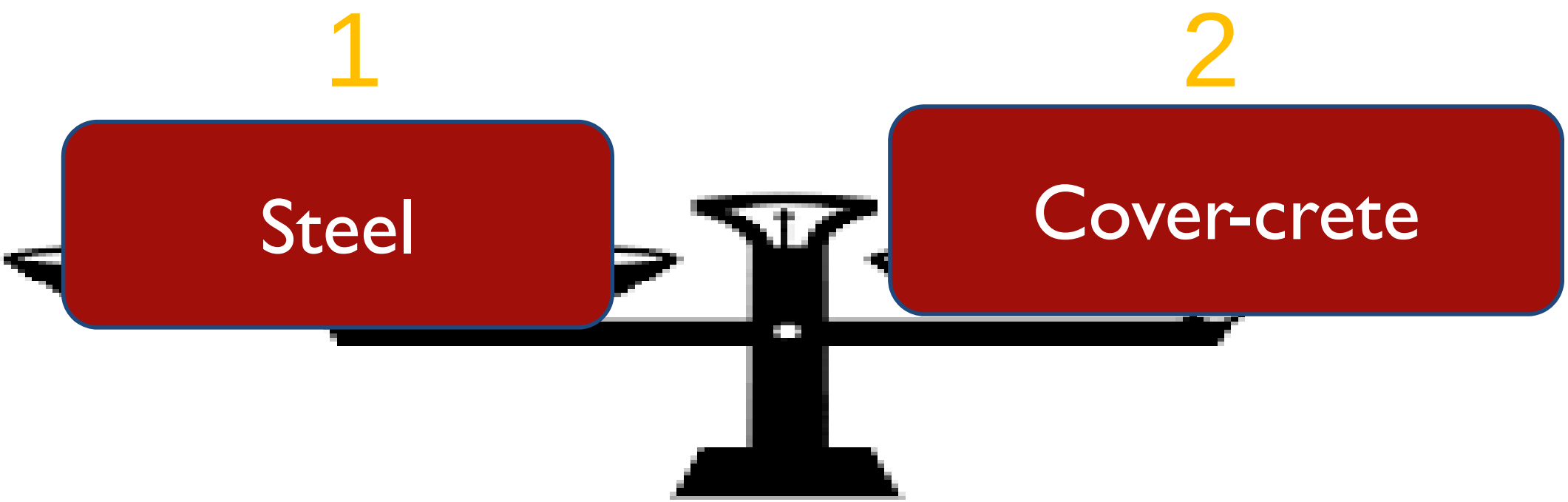
Coast Line : 7516.6 Km

Rs. 102 Lakh Crore
(2020- 2025)
Source: GoI- Union Budget 2020

Construction sector Steel Consumption : 50%

INTRODUCTION

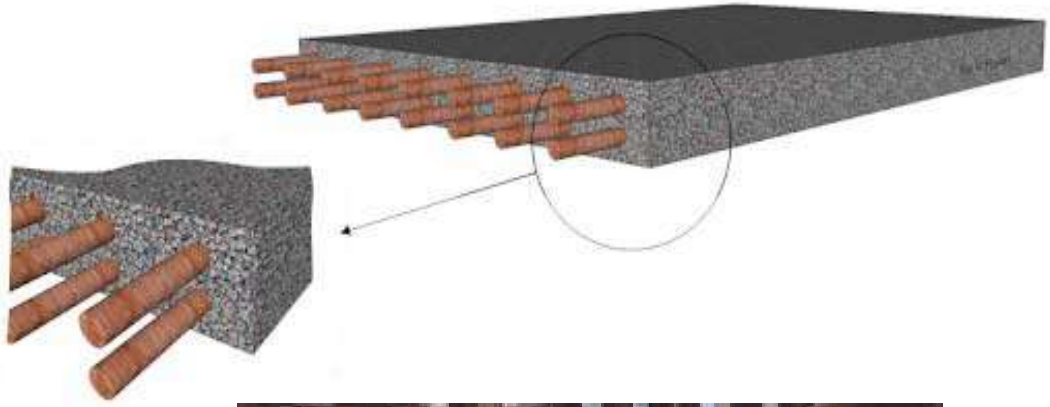
A balanced approach is needed to enhance the durability and service life



Synergistic effects needs to be considered

Source: R.G.Pillai, IITM

BOND STRENGTH - ANALOGY



Skeleton + Muscles = Steel + Concrete

COMMON TYPES OF REINFORCING BARS

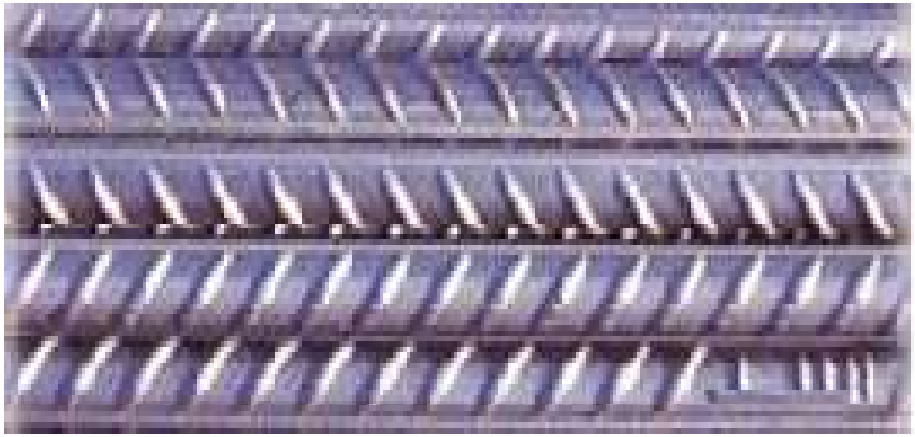
- Plain and ribbed (hot rolled) mild steel bars
  - The ribs improve the mechanical bond.

- Cold twisted deformed (CTD) bars
  - Ribbed low carbon steel bars, twisted to increase the yield strength by work hardening.

- Thermo-mechanically treated (TMT) bars
  - Bars with hard high strength surface and a ductile core.
- Galvanized bars, Epoxy-coated bars
- Stainless steel bars (>10.5% chromium)
- Prestressing strands

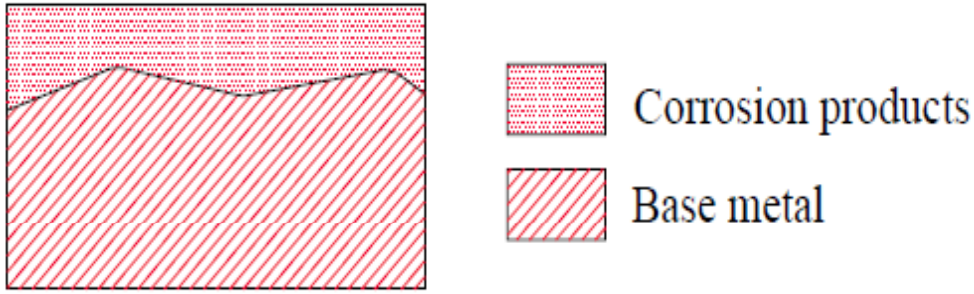
MECHANISM OF PROTECTION OF STEEL BY CONCRETE

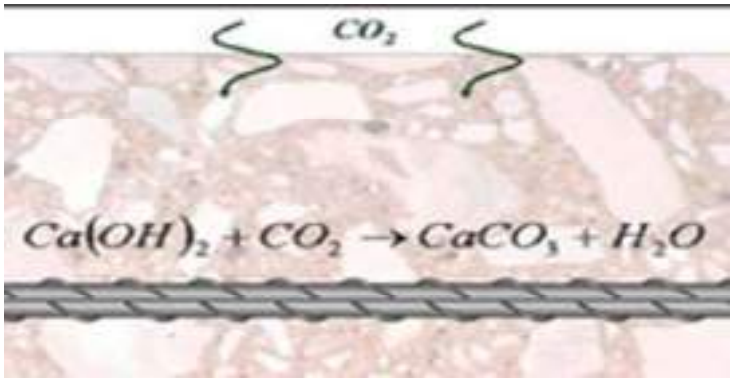
- Reinforcing steel embedded in a chloride free cement concrete - good quality cover - exhibits a high degree of resistance to corrosion.
- Concrete cover provides - chemical and physical barrier
- The ‘chemical barrier’ is the high alkalinity of the concrete pore water solution having a pH value of about 13.
- Formation of passive layer around the steel.



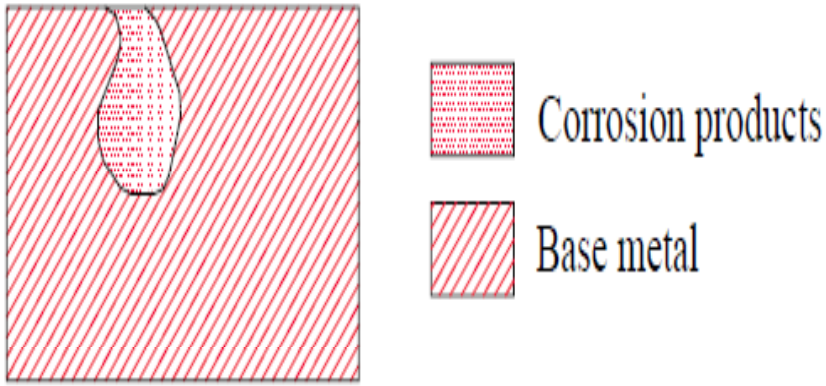
MAJOR CAUSES / TYPES OF CORROSION IN CONCRETE STRUCTURES

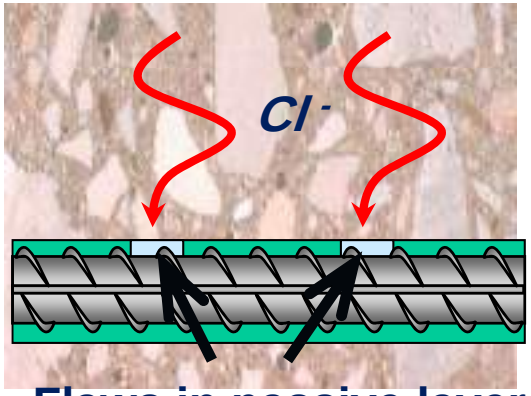
- Carbonation-induced corrosion
  - General or uniform section loss



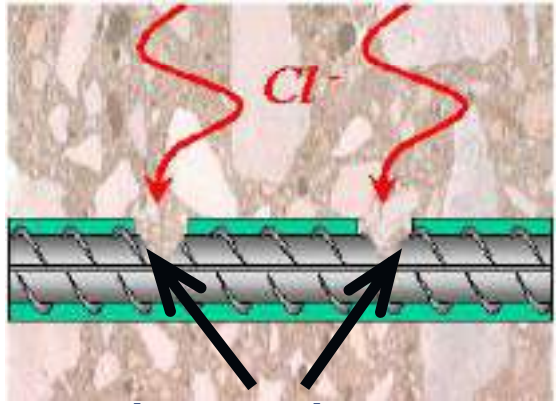


- Chloride-induced corrosion
  - Localized, pitting or non-uniform section loss





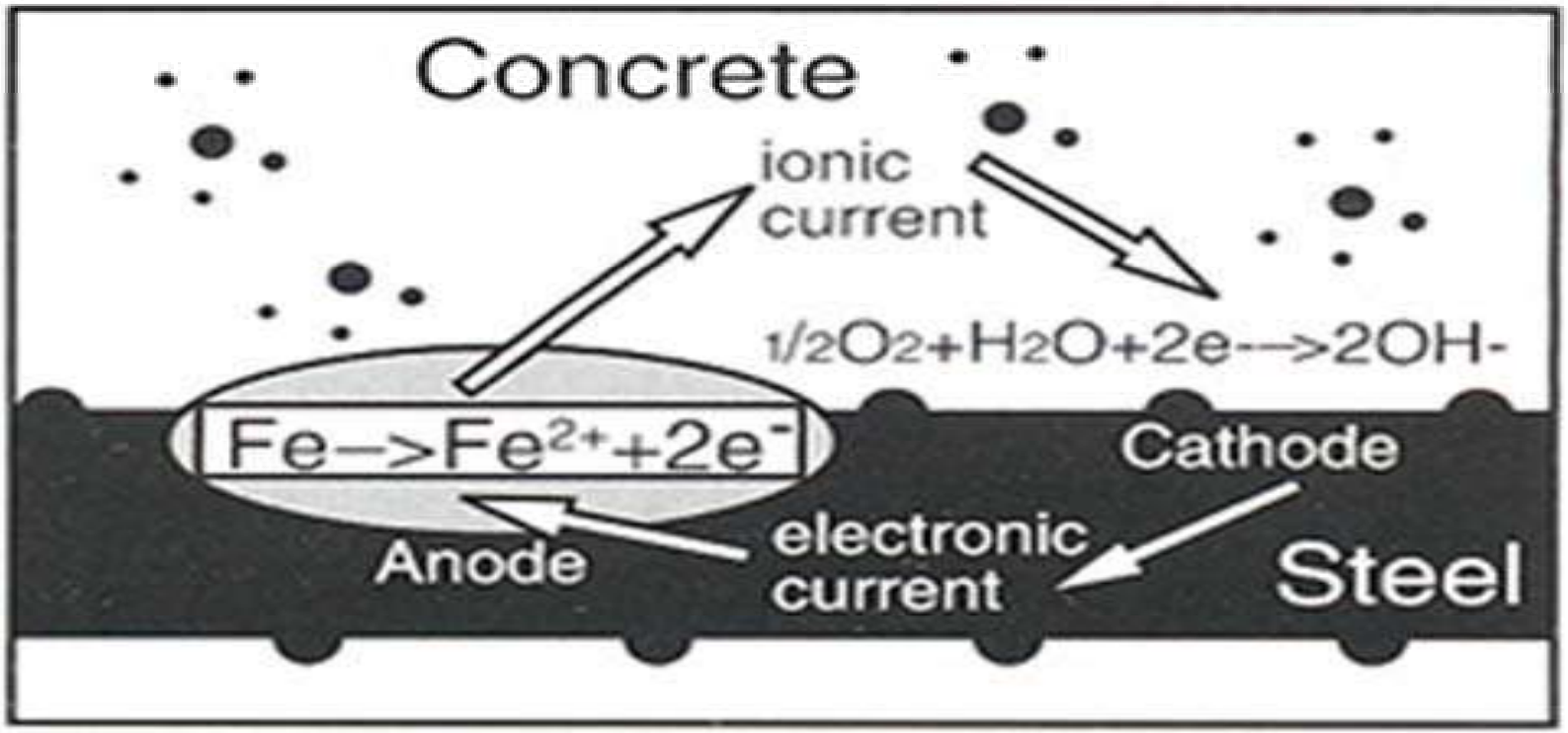
Flaws in passive layer and high chloride content



Pits growing at various locations

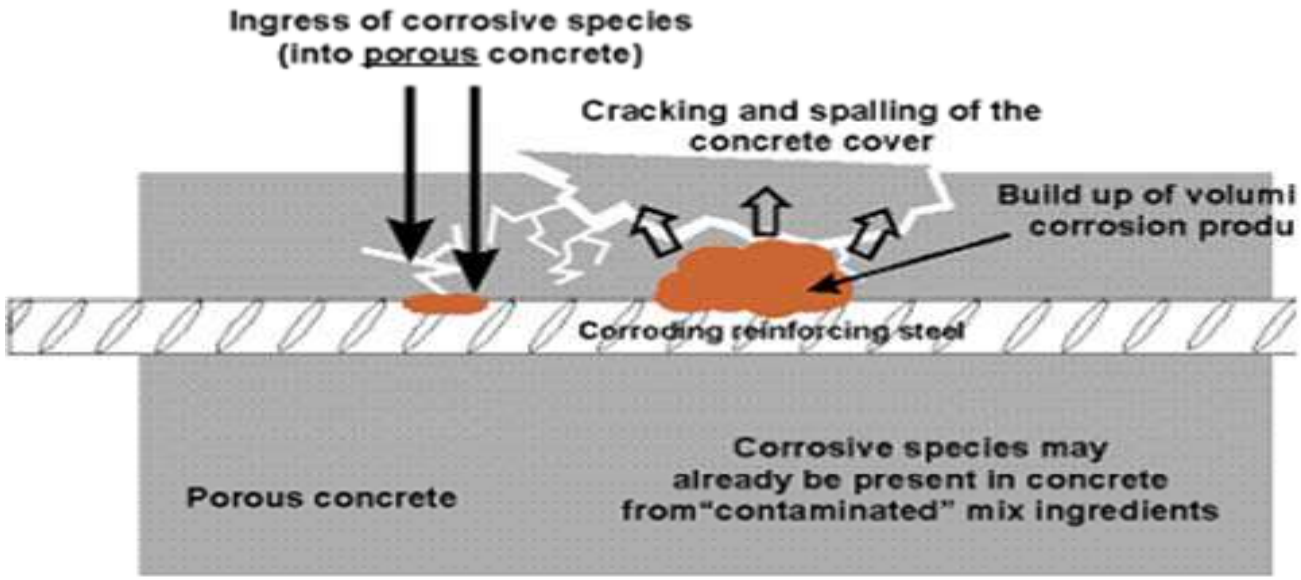
Source: R.G.Pillai, IITM

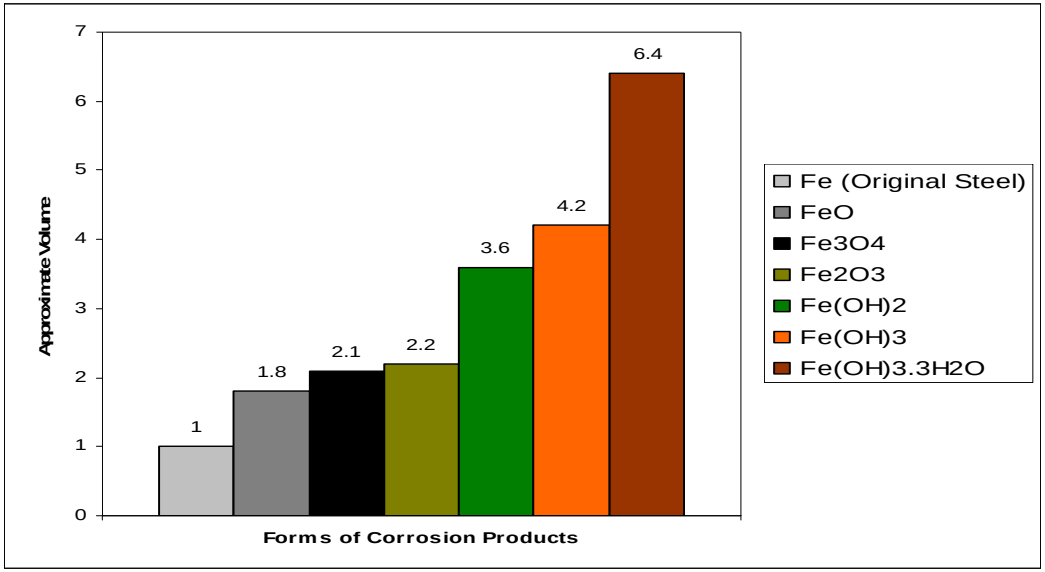
MECHANISM OF CORROSION OF STEEL IN CONCRETE



Corrosion of Steel in Water with Oxygen

MECHANISM OF CORROSION OF STEEL IN CONCRETE

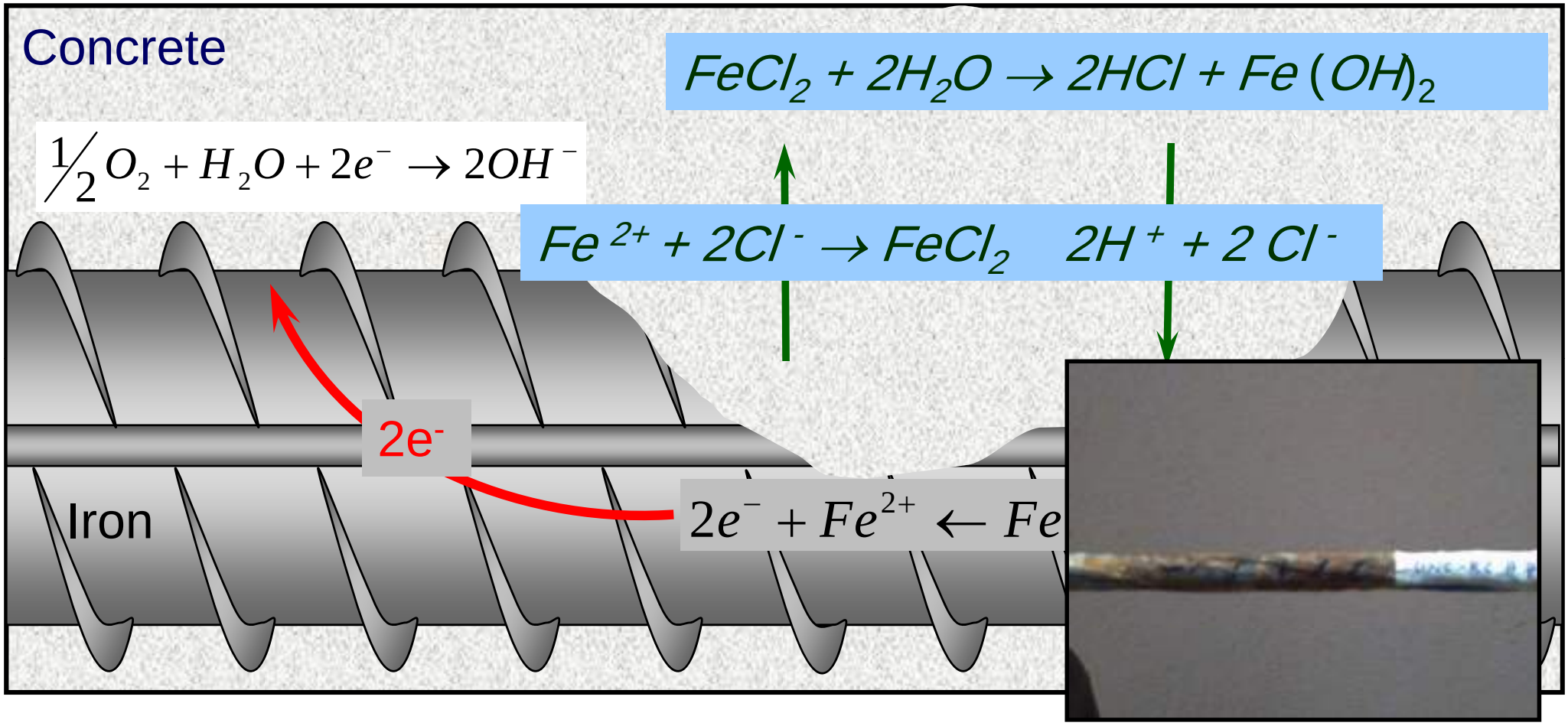




PRESENCE OF CHLORIDES

- Chlorides can be admixed into the concrete
  - Fine and coarse aggregate
  - Mixing water
  - Salt laden air (marine environment)
- The free chlorides present in the pore water solution will promote the corrosion process in Reinforced Concrete.

CHLORIDE-INDUCED CORROSION



- **The process is regenerating and instead of spreading along the bar, corrosion continues at local anodes and deep pits are formed.**

Damage in Conventionally Reinforced Concrete

a. Reduction in steel diameter and cross– sectional area

- This is the most direct damage resulting from steel corrosion in concrete.
- The magnitude of the stresses carried by the remaining steel increases.

CONSEQUENCES OF CORROSION

b. Rust stains, Cracking, Spalling and Delamination of Concrete.

- This type of damage is due to the formation of rust and its deposition within concrete

SPALLING & DELAMINATION

SPALLING & DELAMINATION

- Damage to the concrete cover is extremely detrimental.
- The corrosion rates can be accelerated to a factor of 10 or more
- It was found that cracking of concrete cover if rust layer deposited around the steel reaches 0.1 to 0.2mm.

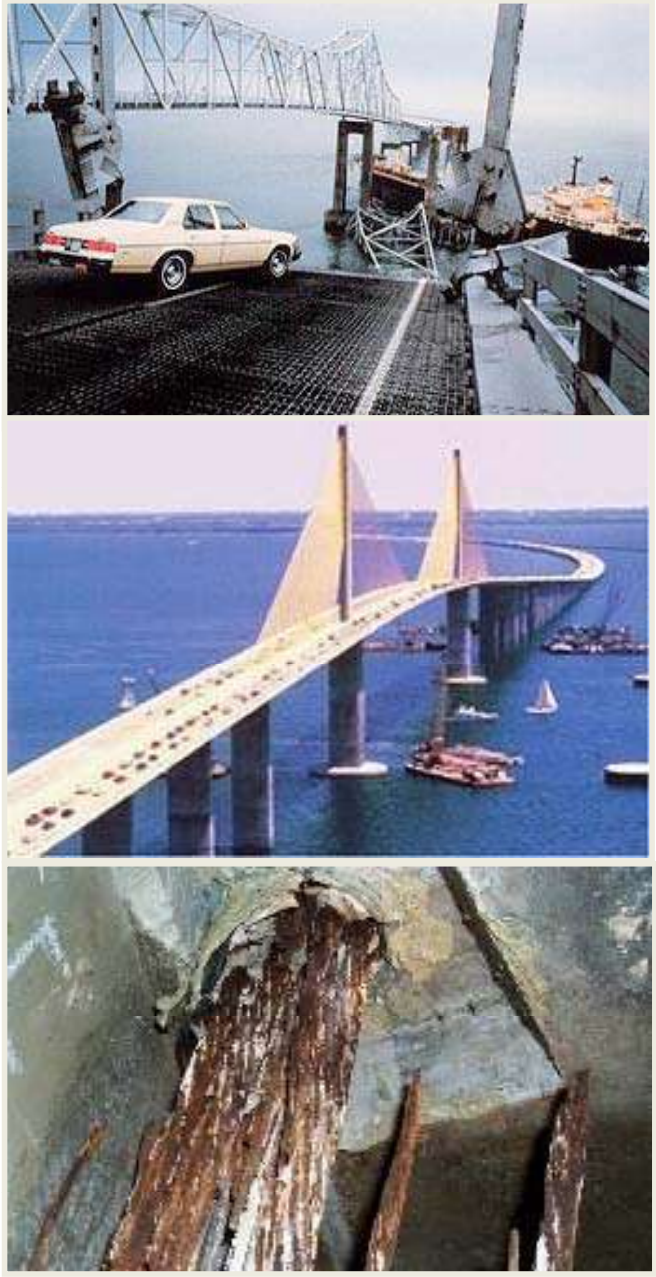
DAMAGE IN PRESTRESSED CONCRETE

- The damaging effects are more severe and catastrophic because of brittle failure of steel associated with a little actual loss of metal.
- These failures result from the simultaneous presence of tensile stresses and a corrosive medium

DAMAGE IN PRESTRESSED CONCRETE

Sunshine Skyway bridge, Florida

- In 1980 this bridge was hit by a cargo ship and a 1200-ft section of bridge fell into the Tampa Bay.
- The bridge was replaced with a segmental, post-tensioned bridge in 1987.
- Only 13 years later, a post-tensioned tendon on the new bridge failed.
- If two tendons fail, a PT bridge can collapse (Pillai 2009).



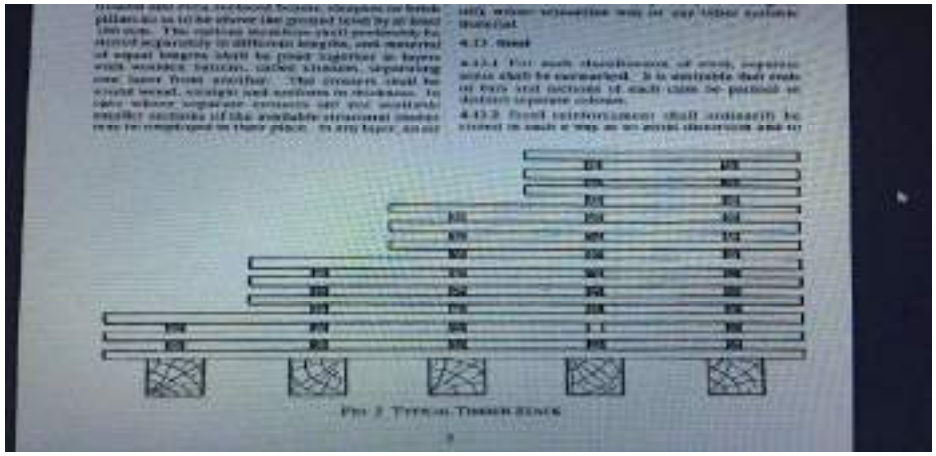
CORROSION PREVENTION IN RC STRUCTURES – GENERAL APPROACHES

- Proper Storage of Reinforcement Rods
- Quality and Durable Concrete :

  Type of cement – SCM – Plasticizer – Good construction practices : Microstructure – Resistivity; Chloride Diffusion coefficient : Concrete Cover

- Protective Coating to Concrete Surfaces
- Addition of Corrosion Inhibitors in Concrete
- Protective Coating to Steel Rebars
- Sacrificial Anode Cathodic Protection

STORAGE OF REINFORCEMET RODS



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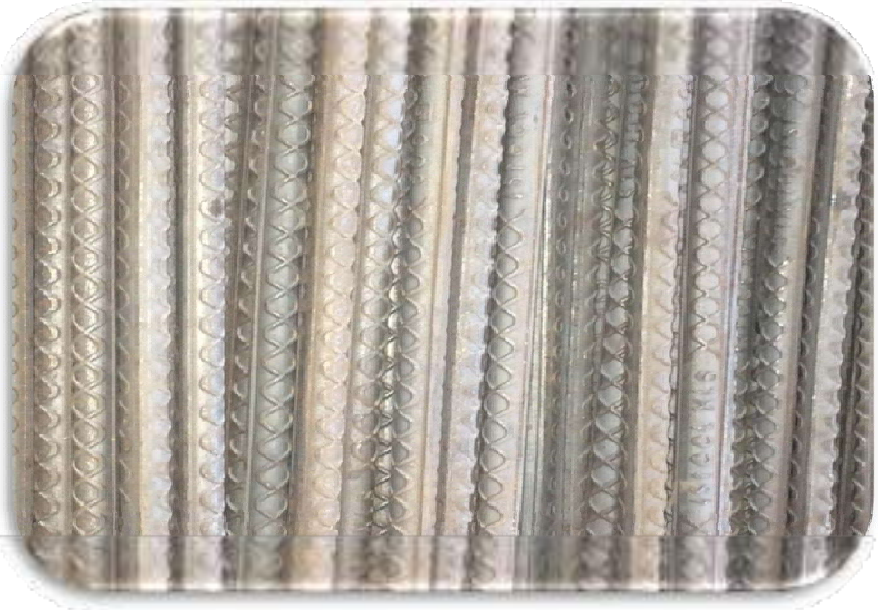
VIEW OF REINFORCEMET : MANUFACTURING



STORAGE OF REINFORCEMET RODS

SURFACE COATINGS ON CONCRETE

- Coating and sealers - protective film over the concrete surface - thickness in the range of 100 to 300 µm.

- Poymer Latex
- Chlorinated rubber
- Coal tar based epoxy
- Epoxy resin
- Polyurethane
- Silicones, Siloxane, Silane

POLYMER CEMENTIOUS COATING ON TERRACE

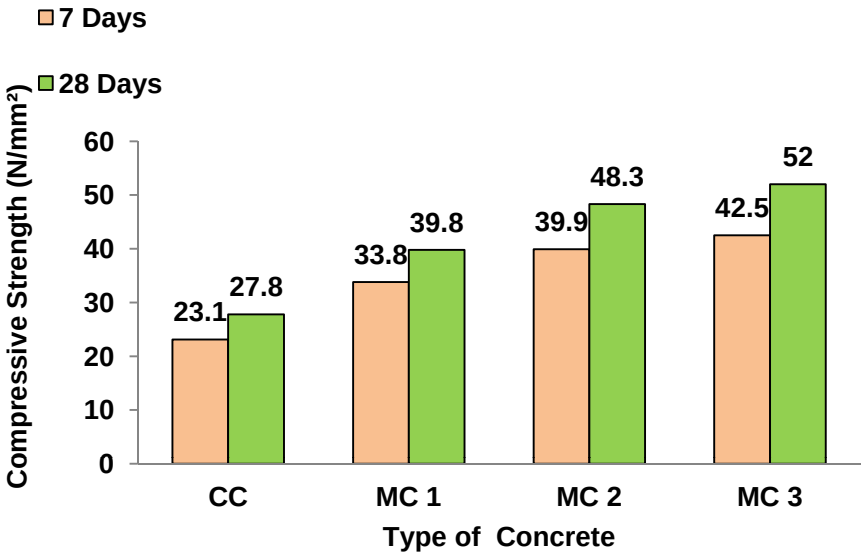
UNCOATED AND COATED BRIDGE ELEMENTS

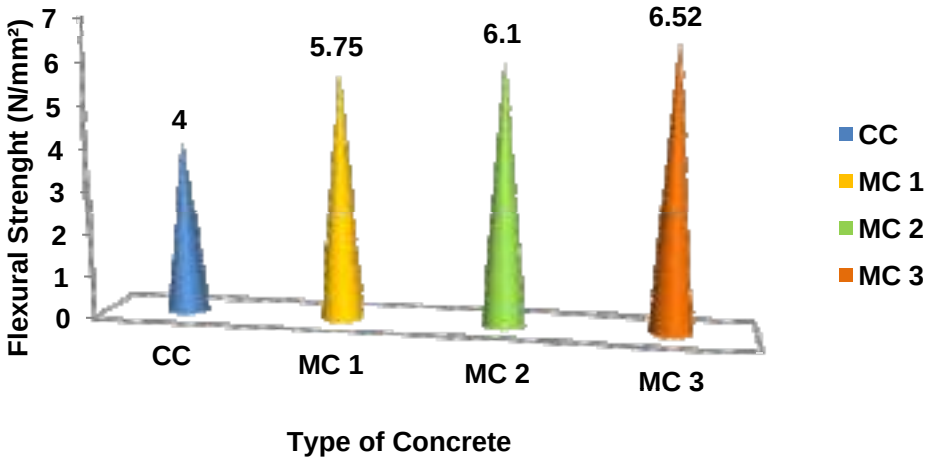
CORROSION INHIBITORS

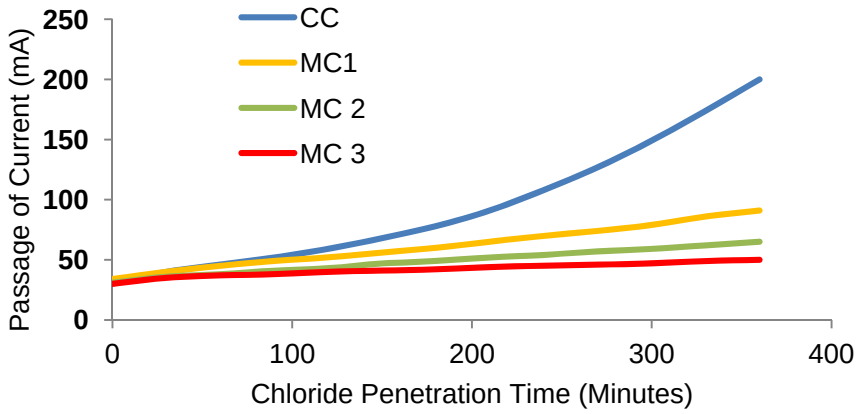
- A corrosion inhibitor – A chemical reduces the corrosion of steel reinforcement rods inside the concrete.
- Types : Anodic, Bipolar, Migration, Vapour phase
- Inhibitors can be
  - Admixed in to mixing water used to prepare concrete
  - Applied on the concrete surface
- Inhibitors can influence fresh concrete and hardened concrete properties.

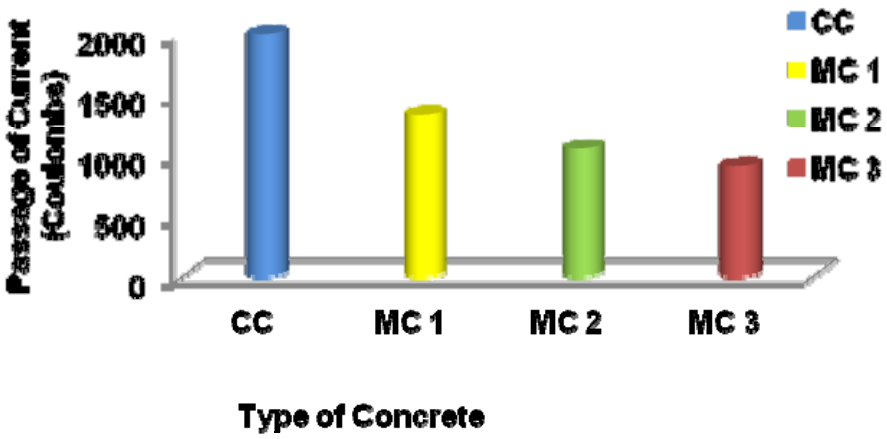
ADDITION OF CORROSION INHIBITOR IN THE MIXTURE MACHINE

STRENGTH AND DURABILITY PERFORMANCE









ANTICORROSIVE COATING SYSTEMS

- Fusion bonded epoxy coating (FBEC)
- Cement polymer composite coating (CPCC)
- Galvanization (GZ)
- Cement polymer anticorrosive coating (CPA)
- Interpenetrating polymer network coating (IPN)
- Inhibited and sealed cement slurry coating (ICS)
- Coating systems of proprietary companies

COATED REBARS - SPECIFICATION

- ASTM A775/A775M – 2001 – Standard Specification for Epoxy-Coated Steel Reinforcing Bars
- IS 13620 – 1993 – Fusion Bonded Epoxy Coated Reinforcing Bars – Specification.
- Code of Practice for Corrosion Protection of Reinforcing Steel using Cement Polymer Composite Coating System (CECRI, 1992).
- IS 12594 – 1988 – Hot-Dip Zinc Coating on Structural Steel Bars for Concrete Reinforcement – Specification.

FUSION BONDED EPOXY COATING PROCESS

Rust removal – Shot Blasting

Quality check before coating

Epoxy Coating – Electrostatic Spray Technique

Epoxy coated bars

FUSION BONDED EPOXY COATING PROCESS

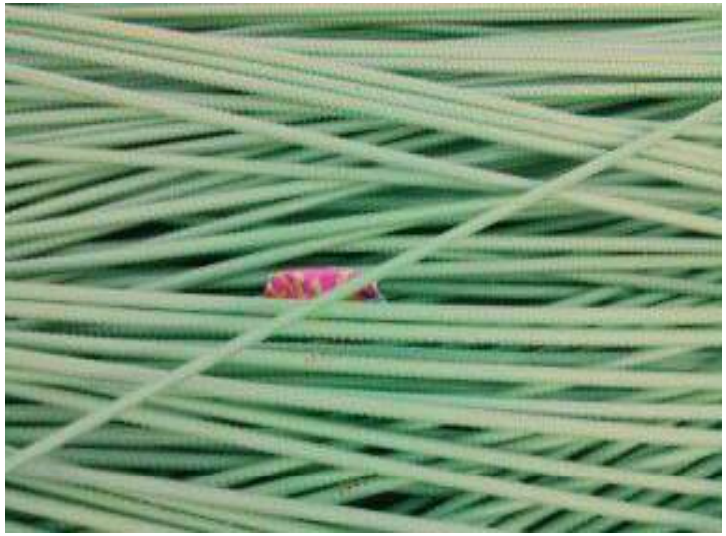
Quality Checks

Packing for Transportation

View of FBEC bars in the site

Fusion Bonded Epoxy Coating (FBEC)





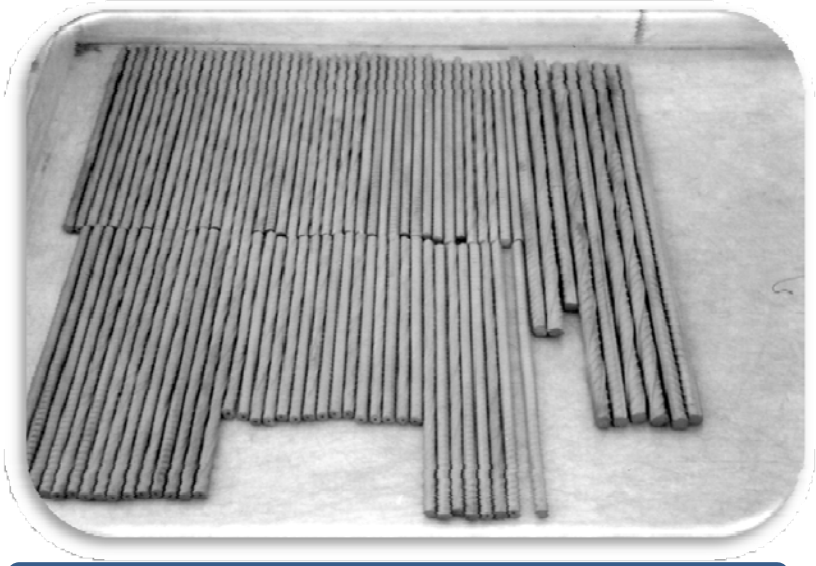

Factory oriented process **Damage to coating** **Quality control at site**

FUSION BONDED EPOXY COATING : CONCERNS

The Bond between Epoxy Coated Rebar and Concrete

Flaw in specification – Followed in spirit

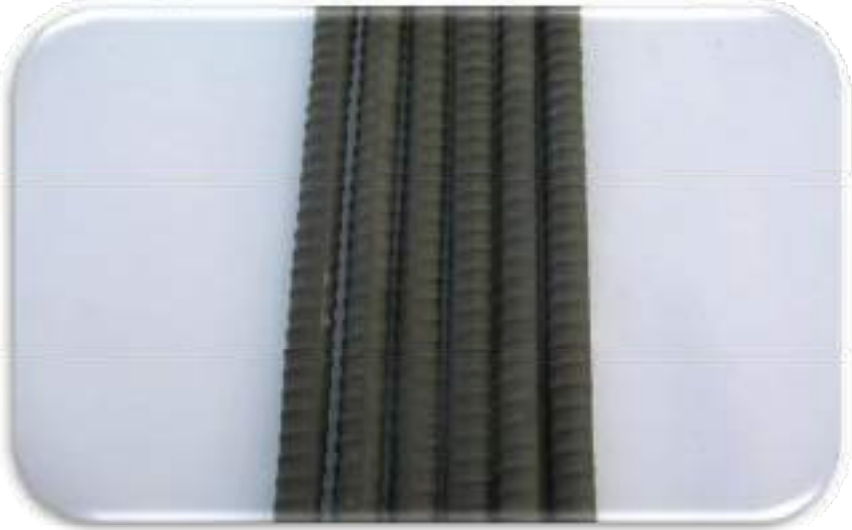
CEMENT POLYMER COMPOSITE COATING PROCESS



Rust Removal – Sand Blasting

Application of Primer Coat

View of Primer coated bars



CPCC Coated Bars

VIEW OF STORAGE OF COATED REBARS IN THE CONSTRUCTION SITE

VIEW OF FABRICATED COATED REBARS

POOR STORAGE AND HANDLING PRACTICES AT SITE






GALVANIZED STEEL REBARS

- **Metallic coating**
- **Sacrificial protection to steel rebars**
- **Factory process**

Deep Tunnel Sewage System, Singapore (2008)

New Watford Bridge, Bermuda (1983)

Boca Chica Bridge & Athens Bridge, FL, USA (1972)

The Lotus Temple, New Delhi, India (1986)

The Parliament House, Australia (1988)

Curtis Road Bridge, Michigan (1976)

VIEW OF GALVANIZED REBARS AT SITE

HOT-DIP GALVANIZATION (HDG)

Rebar with rust layers

↓

Rust removal by acid pickling
(HCL + water + inhibitor)

↓

Acid neutralization by cleaning with water

↓

Immersion in Flux Solution
(Zinc Chloride +Ammonium Chloride)

↓

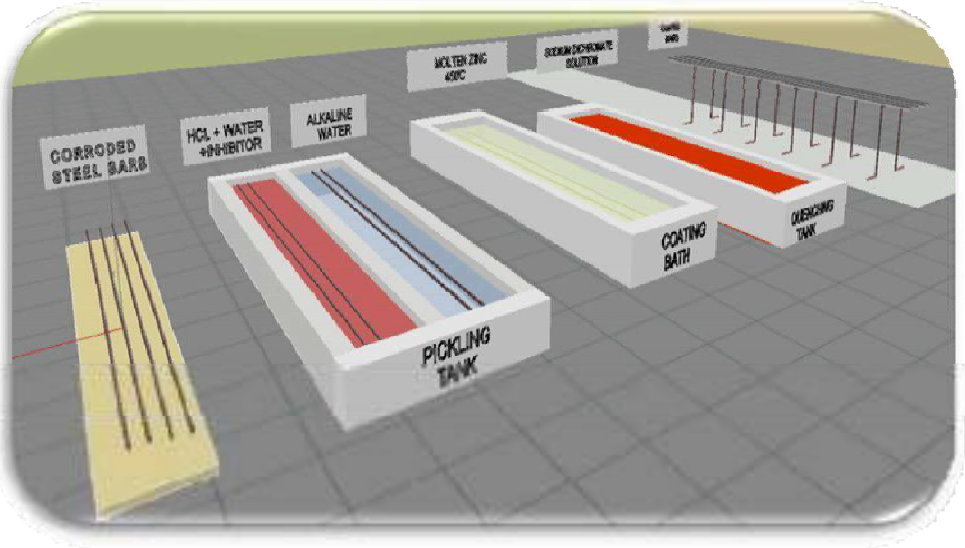
Immersion in Molten Zinc (450°C)
Coating thickness : 75 to 125 microns

↓

Quenching in Sodium Dichromate solution

↓

Treatment duration : 2 hours

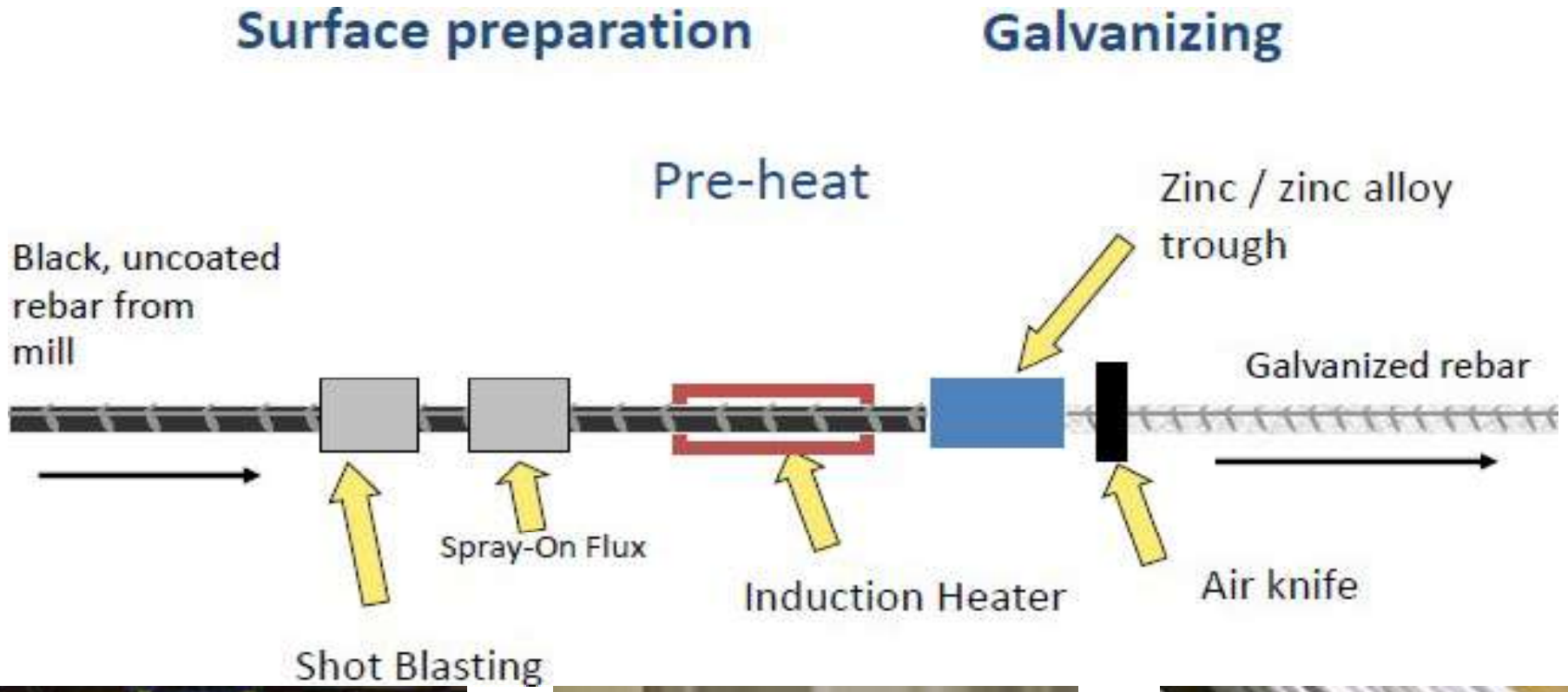


GALVANIZATION PROCESS

Rust Removal – Acid Pickling

Galvanized Rebars

CONTINUOUS GALVANIZATION (CG)



Source: www.azz.com

CEMENT POLYMER ANTICORROSIVE COATING PROCESS

Rusted rebar

↓

Loose rust removal by steel wire brush

↓

Application of two coats of Anticorrosive polymer cementitious coating at 6-12 hours interval

↓

Treated rebar
Coating thickness : 250±25 microns
Treatment duration : 12 hours

CEMENT POLYMER ANTICORROSIVE COATING PROCESS

Loose Rust Removal – Steel Wire Brush Cleaning

Application of CPA Coating

CEMENT POLYMER ANTICORROSIVE COATED BARS

CEMENT POLYMER ANTICORROSIVE COATED BARS

CPAC BARS AFTER MARINE EXPOSURE

Uncoated and CPA coated bars after 8 months marine exposure at Muttukadu, Chennai

REHABILITATION OF CORRODED REBARS – CPA COATING

COATED REBARS : PERFORMANCE EVALUATION TESTS

- Chemical Resistance test (Institute)
- Accelerated CorrosionTest (Institute)
- Impressed VoltageTest
- Macrocell Corrosion Test
- Open Circuit Potential Test
- Bond Strength to Concrete Test (Institute)
- Impact Test (site)
- Adhesion Test (site)
- Atmospheric Exposure Test

PERFORMANCE EVALUATION TESTS : T20

Chemical Resistance Test

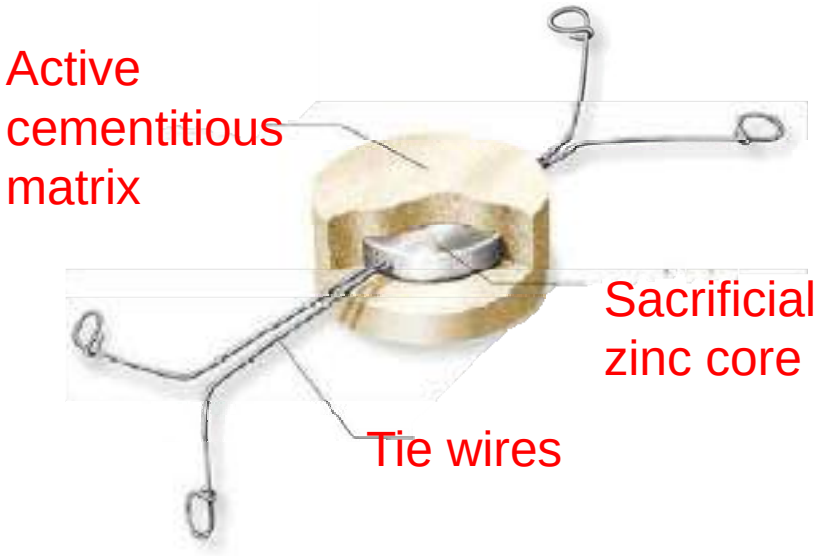
Accelerated corrosion Test

Bond Strength Test

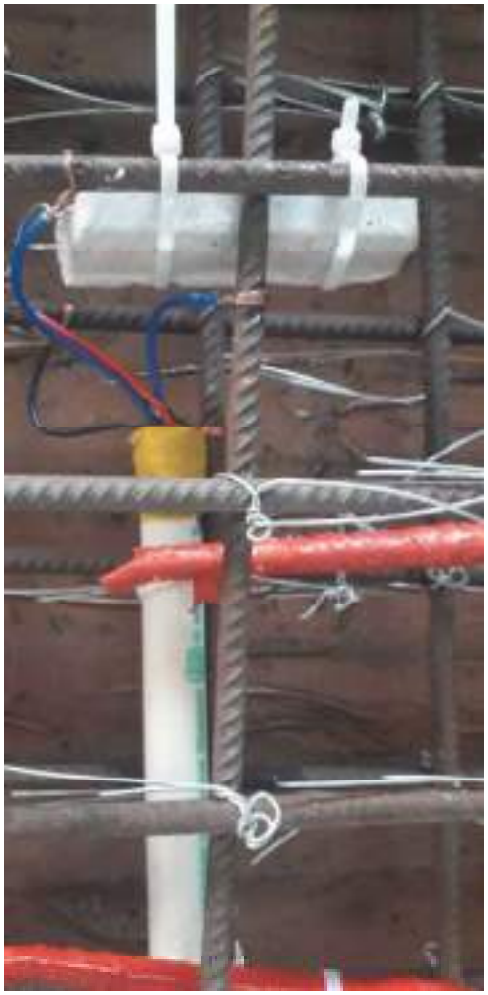
Impact resistance

Coating flexibility

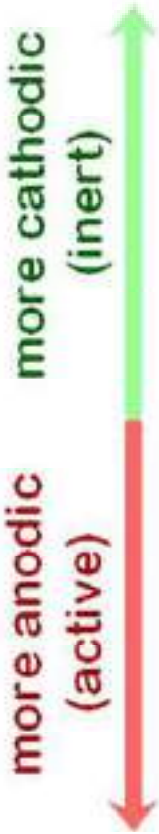
SACP – SACRIFICIAL ANODE CATHODIC PROTECTION



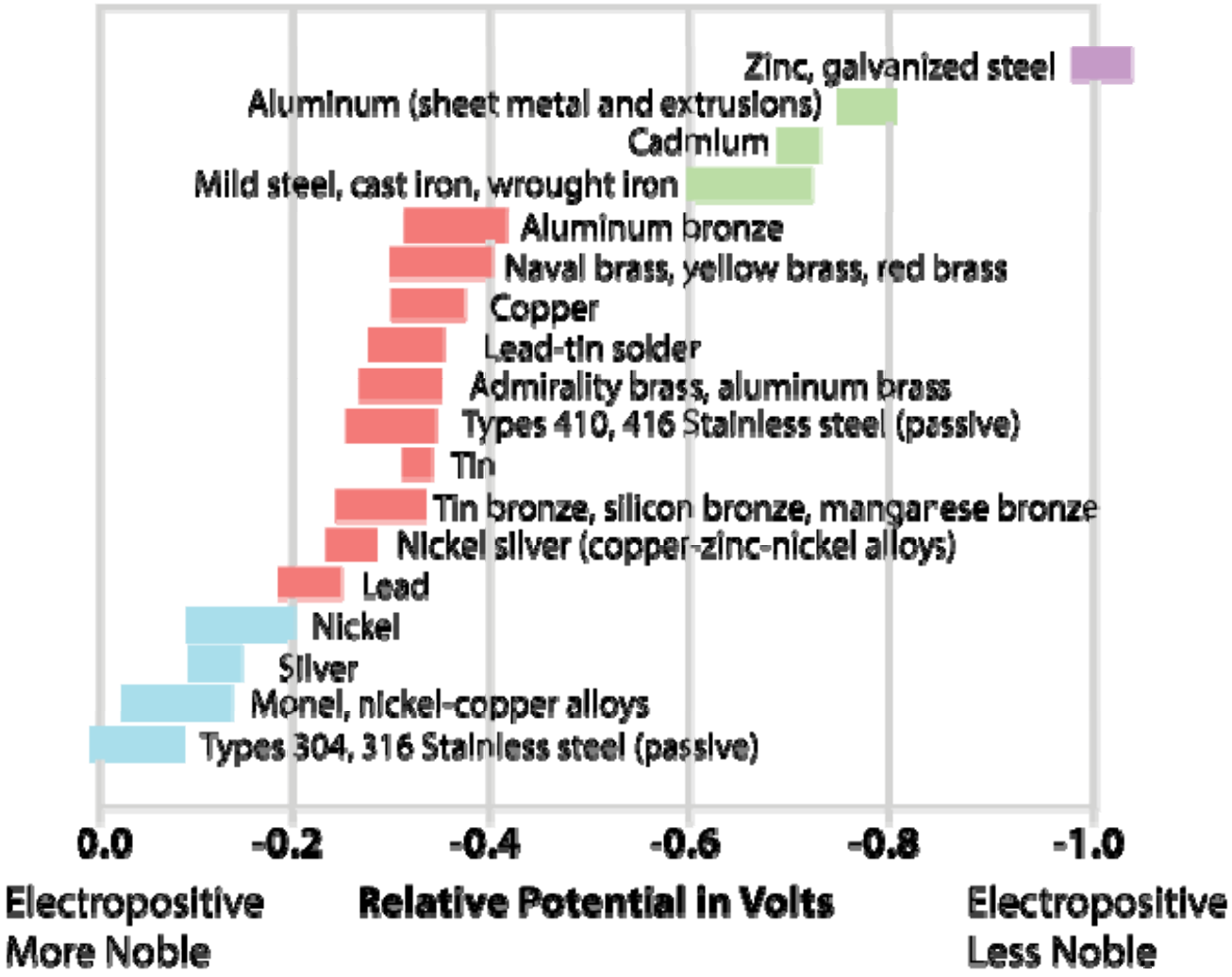
SACP – SACRIFICIAL ANODE CATHODIC PROTECTION



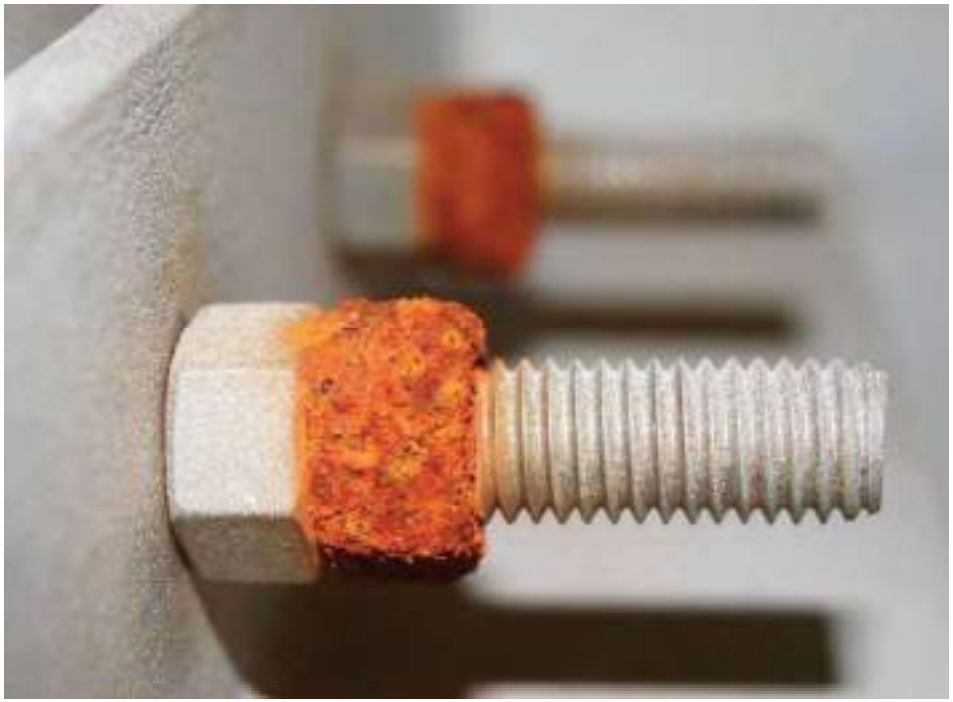
GALVANIC SERIES



Platinum
Gold
Graphite
Titanium
Silver
316 Stainless Steel
Nickel (passive)
Copper
Nickel (active)
Tin
Lead
316 Stainless Steel
Iron/Steel
Aluminum Alloys
Cadmium
Zinc
Magnesium



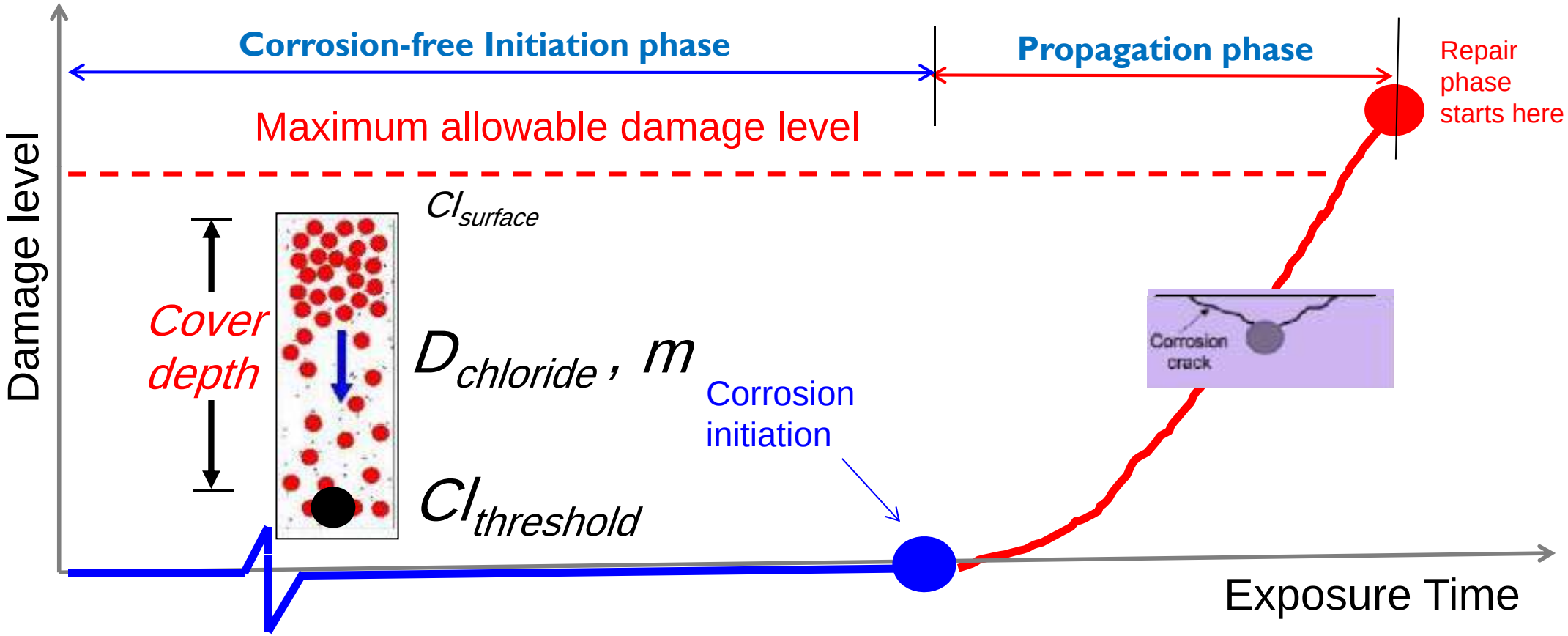
GALVANIC CORROSION



When two dissimilar metals are in contact, more anodic metal preferentially corrode in presence of an electrolyte
Zinc corrodes when in contact with iron

MICROBIAL INDUCED CORROSION (MIC)

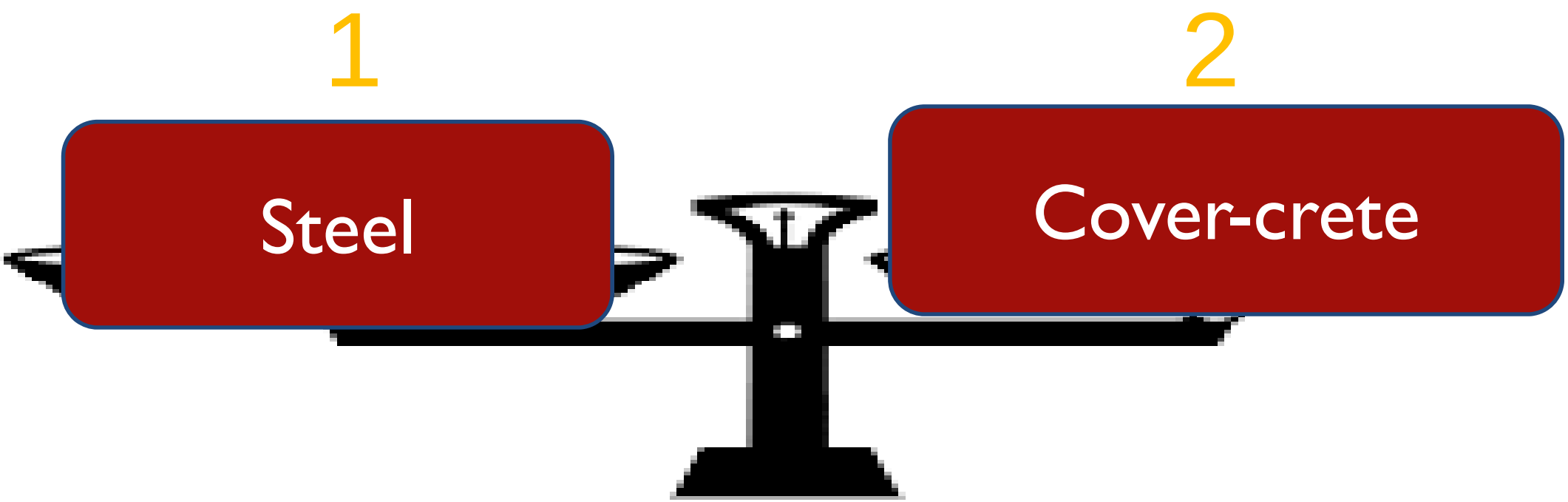
Service life of structures exposed to chlorides



Source: R.G.Pillai, IITM

INTRODUCTION

A balanced approach is needed to enhance the durability and service life



Synergistic effects needs to be considered

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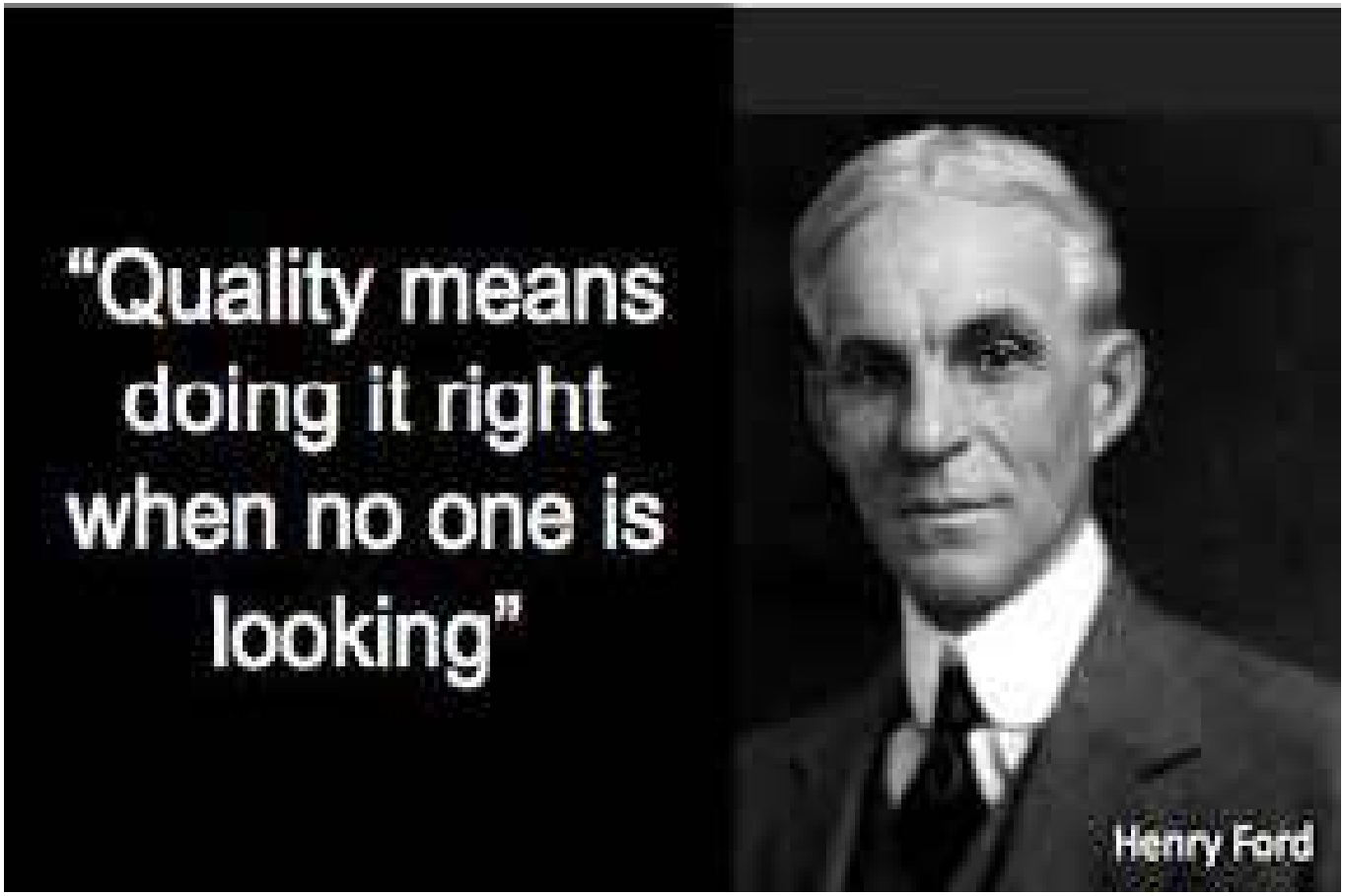
SUMMARY

- Reinforced Concrete is very much alive.
- Integral action of Steel rebars and Concrete is vital for stability and Durability of Reinforced Concrete Structures.
- There is a definite need to protect steel rebars inside the concrete.
- Protective coating to steel rebars and addition of Corrosion inhibitor in concrete are efficient methods to protect steel rebars.
- Adoption of corrosion control strategies needs selection of appropriate method, meticulous planning and execution.
- Corrosion protection methods are not to compromise quality and durable concrete.

WHAT IS QUALITY?



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