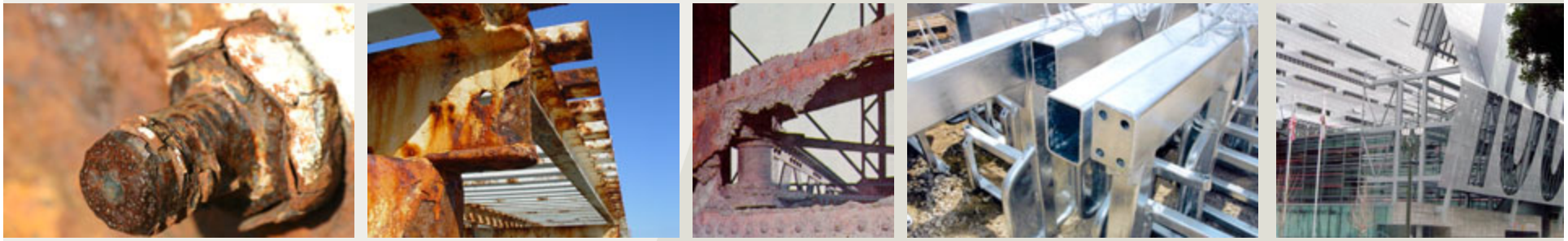

Corrosion Protection

Basic corrosion theory and protection methods

Author: Dr. Thomas J. Langill

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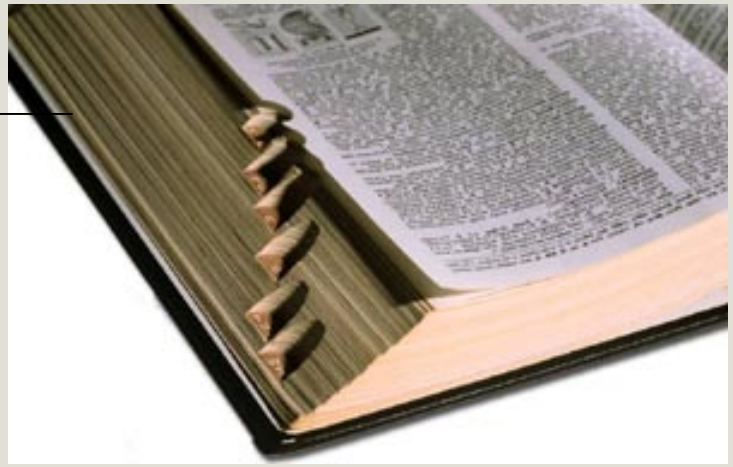
Corrosion & Corrosion Control

- **What is Corrosion**
- **How/Why Does Corrosion Occur**
- **Corrosion Costs**
- **Forms of Corrosion**
- **Corrosion Control Methods**
- **Hot-dip Galvanizing (HDG)**
  - Process
  - Coating Characteristics
  - Performance in Corrosive Environments
- **Galvanized Steel in Action**

What is Corrosion

- **Corrosion (n)**
  - The chemical or electrochemical reaction between a material and its environments that produces a deterioration of the material and its properties.



The Galvanic Series

CORRODED END
Anodic or less nobel

Magnesium
Zinc
Aluminum
Cadmium
Steel
Lead
Tin
Nickel
Brass
Bronzes
Copper
Nickel-Copper Alloys
Stainless Steels (passive)
Silver
Gold
Platinum

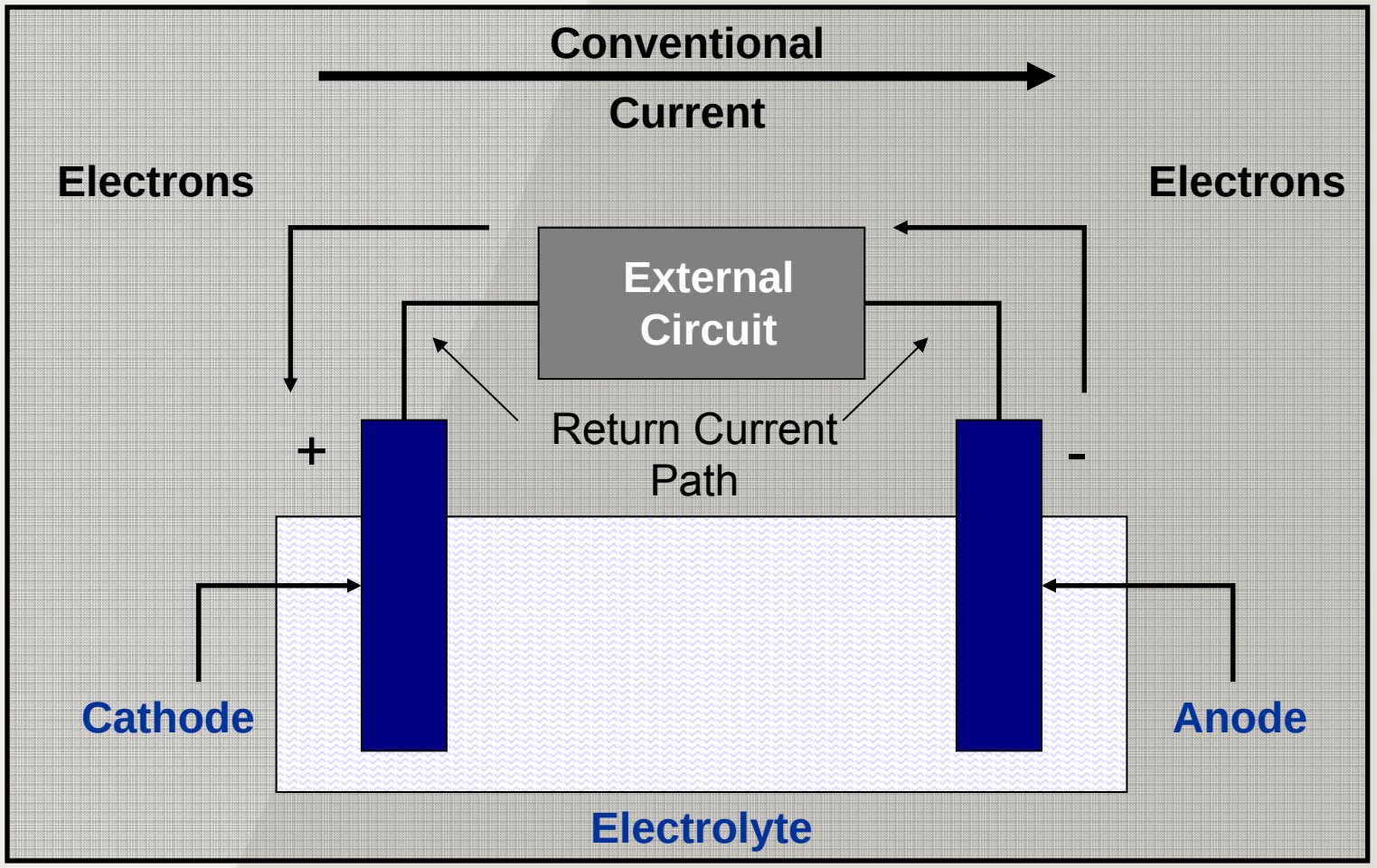
PROTECTED END
Cathodic or most nobel

ZINC - Anode

STEEL - Cathode

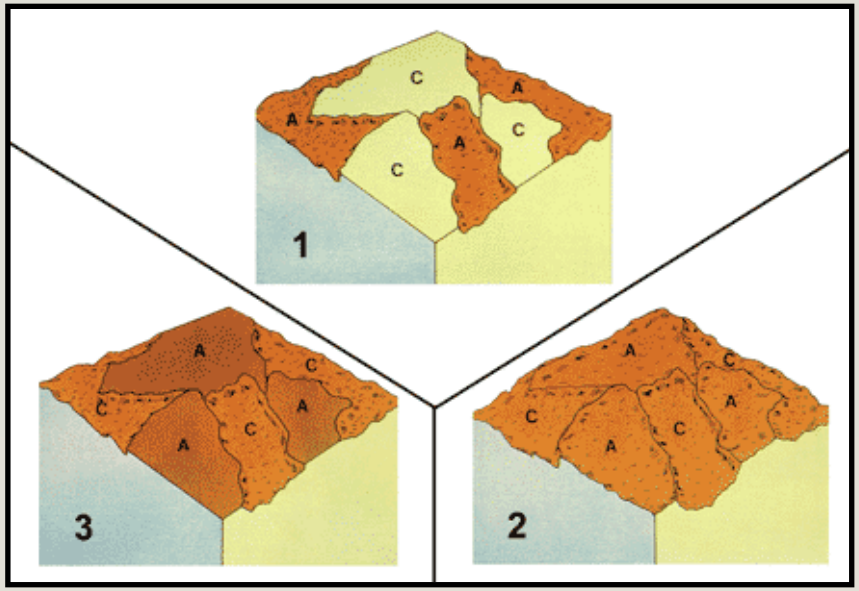
This arrangement of metals determines what metal will be the anode and cathode when the two are put in a electrolytic cell (arrangement dependent on salt water as electrolyte).

Bimetallic Couple



Bare Steel Corrosion

- Microscopic anodic and cathodic areas exist on a single piece of steel.
- As anodic areas corrode, new material of different composition is exposed and thus has a different electrical potential



Forms of Corrosion

- **General**
  - Identified by uniform formation of corrosion products that causes a even thinning of the substrate steel
- **Localized**
  - Caused by difference in chemical or physical conditions between adjoining sites
- **Bacterial**
  - Caused by the formation of bacteria with an affinity for metals on the surface of the steel
- **Galvanic/Dissimilar Metal**
  - Caused when dissimilar metals come in contact, the difference in electrical potential sets up a corrosion cell or a bimetallic couple

Corrosion Costs

Direct Costs

- **NACE, CC Technologies, & FHWA jointly produced a report in 2001 detailing the costs of corrosion**
  - $276 billion USD annually
  - 3.1% of US GDP (1998)

Indirect Costs

- **Catastrophe**
  - Public safety, property damage, environmental contamination
- **Natural Resources**
  - Waste production, increased energy consumption
- **Public Outcry**
  - Traffic, inconvenience

Methods of Corrosion Control

- **Barrier Protection**
  - Provided by a protective coating that acts as a barrier between corrosive elements and the metal substrate
- **Cathodic Protection**
  - Employs protecting one metal by connecting it to another metal that is more anodic, according to the galvanic series
- **Corrosion Resistant Materials**
  - Materials inherently resistant to corrosion in certain environments

Barrier Protection

- Paint
- Powder Coatings
- Galvanizing

Cathodic Protection

- **Impressed Current**
- **Galvanic Sacrificial Anode**
- **Galvanic Zinc Application**
  - Zinc Metallizing
  - Zinc-rich Paints
  - Hot-dip Galvanizing

Cathodic Protection

- **Impressed Current**
  - External source of direct current power is connected (or impressed) between the structure to be protected and the ground bed (anode)
  - Ideal impressed current systems use ground bed material that can discharge large amounts of current and yet still have a long life expectancy.

Cathodic Protection

- **Galvanic Sacrificial Anode**
  - Pieces of an active metal such as magnesium or zinc are placed in contact with the corrosive environment and are electrically connected to the structure to be protected
  - Example: Docked Naval Ships

Cathodic Protection

- **Galvanic Zinc Application**
  - **Zinc Metallizing (plating)**
    - Feeding zinc into a heated gun, where it is melted and sprayed on a structure or part using combustion gases and/or auxiliary compressed air
  - **Zinc-rich Paints**
    - Zinc-rich paints contain various amounts of metallic zinc dust and are applied by brush or spray to properly prepared steel
  - **Hot-dip Galvanizing**
    - Complete immersion of steel into a kettle/vessel of molten zinc

Galvanic Zinc Applications

Zinc Metallizing

Zinc-rich Paints

Hot-dip Galvanizing Process

- Surface Preparation
- Galvanizing
- Inspection

Surface Preparation

Zinc-iron metallurgical bond only occurs on clean steel

- **Degreasing**
  - Removes dirt, oils, organic residue
- **Pickling**
  - Removes mill scale and oxides
- **Fluxing**
  - Mild cleaning, provides protective layer

Degreasing/Caustic cleaning

Galvanizing

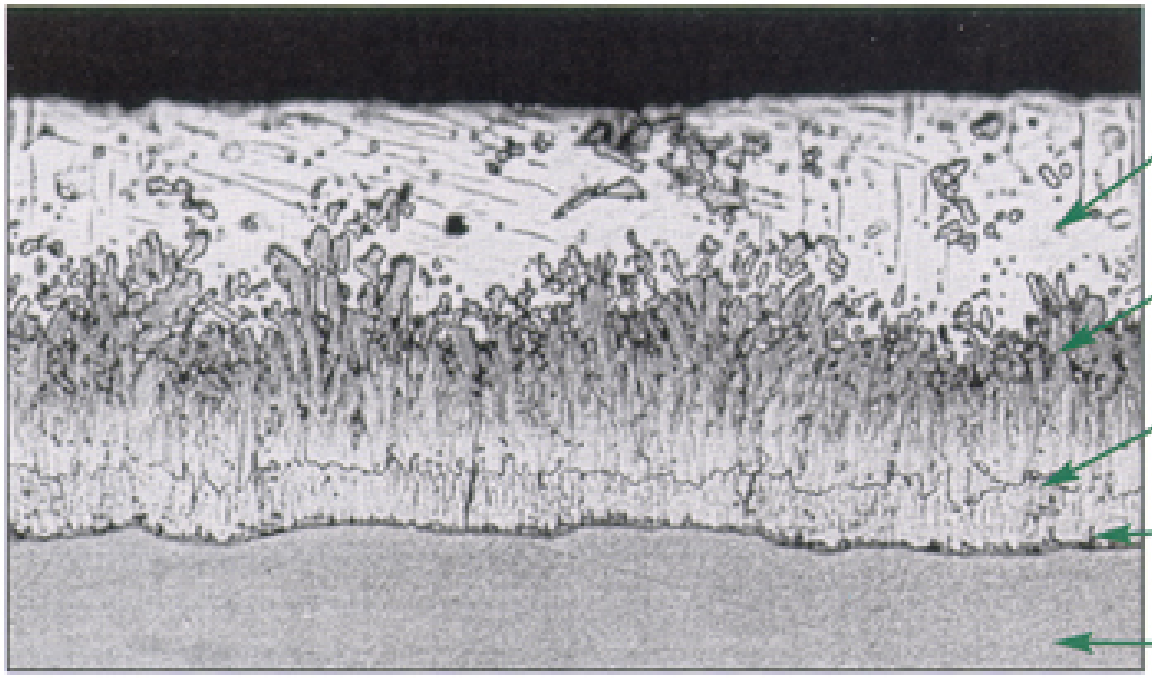
- Steel articles are immersed in a bath of molten zinc (≈ 830 F)
- > 98% pure zinc, minor elements added for coating properties (Al, Bi, Ni)
- Zinc reacts with iron in the steel to form galvanized coating.

Zinc bath removal

Inspection

- Steel articles are inspected after galvanizing to verify conformance to appropriate specs.
- Surface defects easily identified through visual inspection.
- Coating thickness verified through magnetic thickness gauge readings.

Metallurgical Bond



Eta
(100% Zn)
70 DPN Hardness

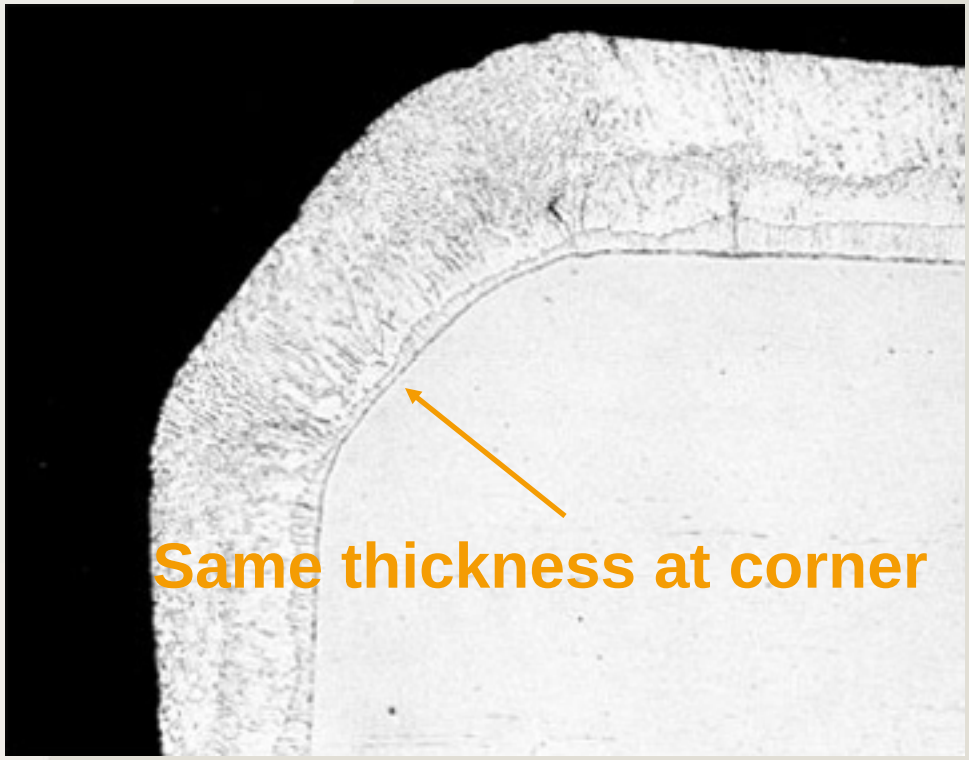
Zeta
(94% Zn 6% Fe)
179 DPN Hardness

Delta
(90% Zn 10% Fe)
244 DPN Hardness

Gamma
(75% Zn 25% Fe)
250 DPN Hardness

Base Steel
159 DPN Hardness

Edge Protection

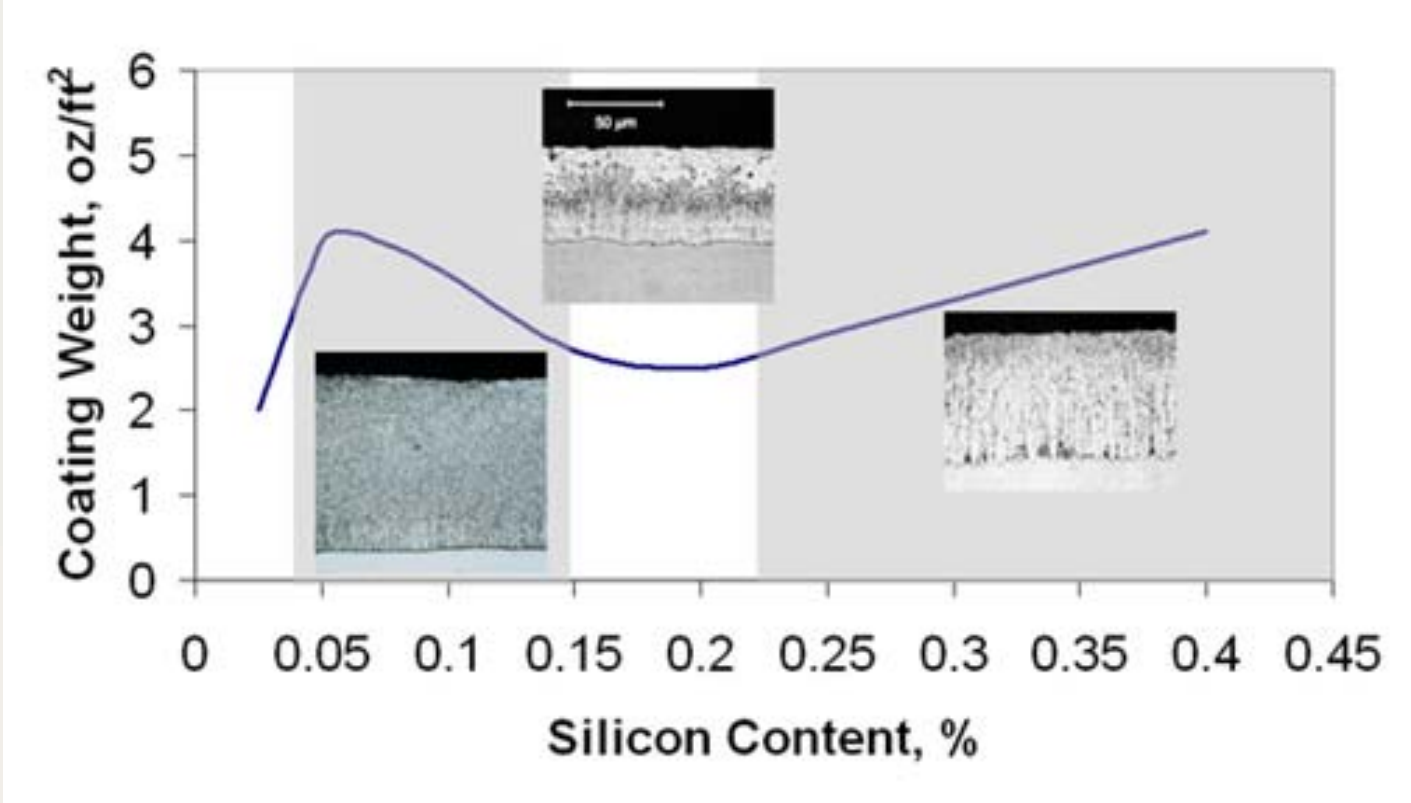


Micrograph of galvanized edge

Influencers of Coating Development

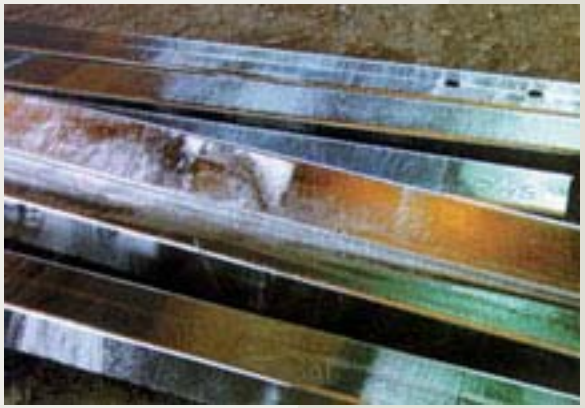
- **Steel Surface Conditions**
- **Steel Chemistry**
  - Silicon
  - Phosphorous

The Sandelin Curve



Coating Appearance

Newly Galvanized
No Spangle



Newly Galvanized
Dull Coating

Newly Galvanized
Highly Spangle

Newly Installed
Shiny & Dull Coating

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The Zinc Patina

- Forms as zinc reacts with the environment
- Consists of zinc oxide, zinc hydroxide, and zinc carbonate
- Protects the galvanized coating by providing an additional layer of corrosion resistance

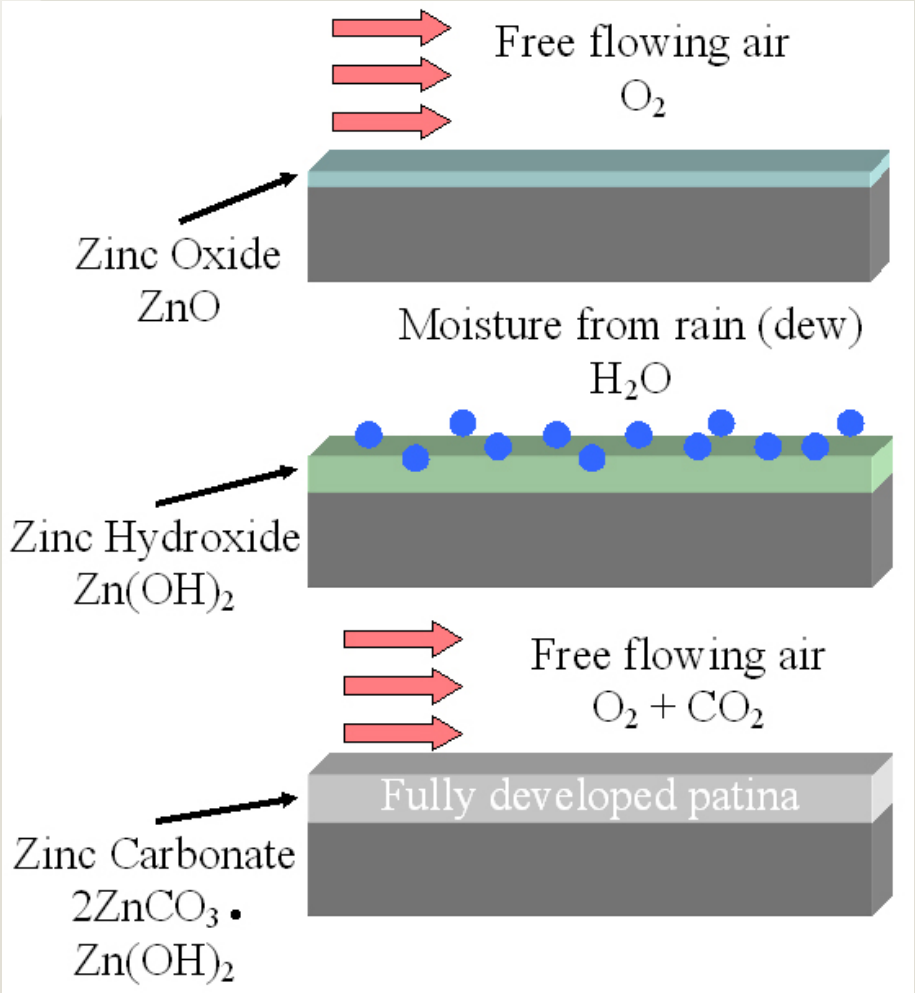
Passivation Cycle

Time

0 – 48 hrs. 1

48 hrs. – 6 mo. 2

6 mo. – 2 yrs. 3



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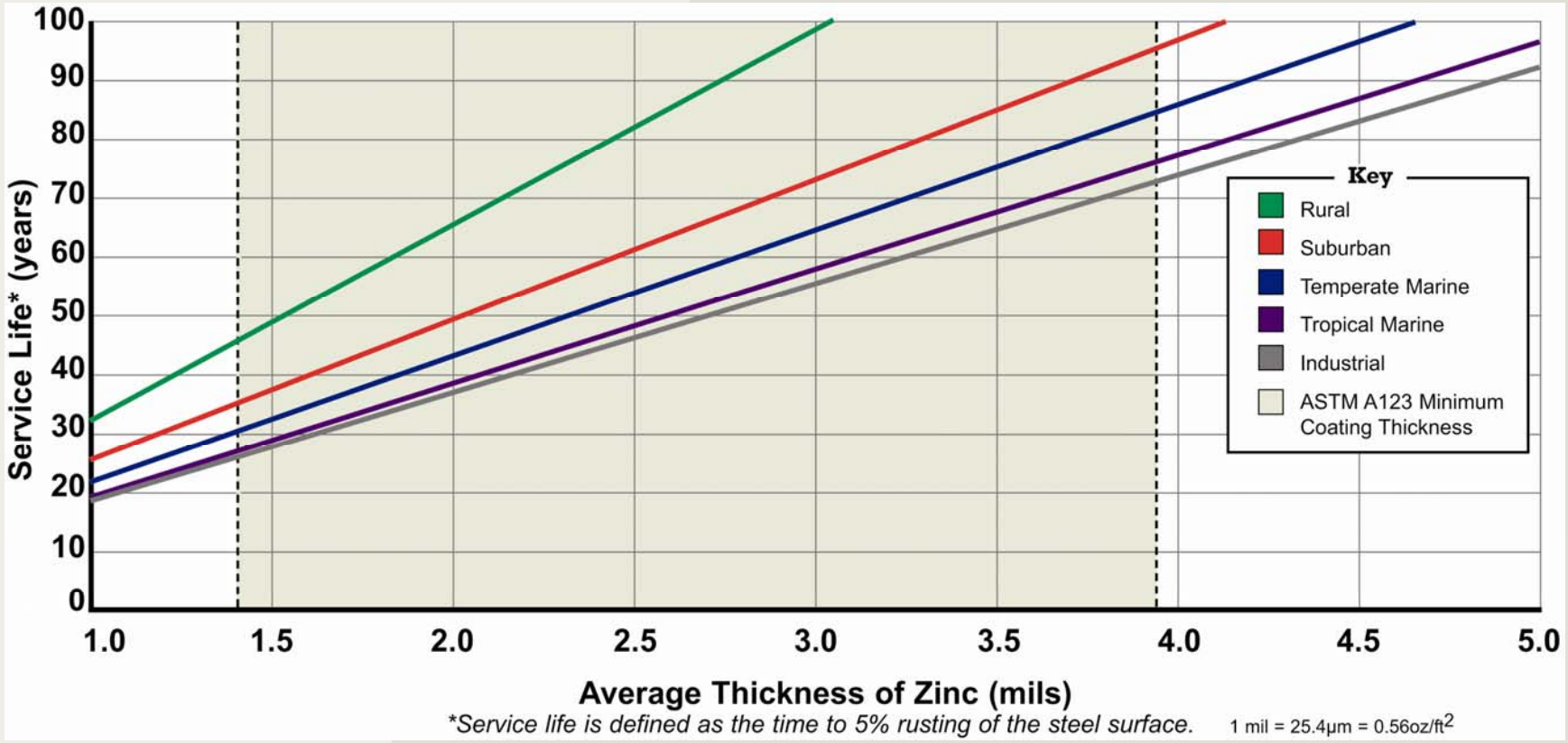
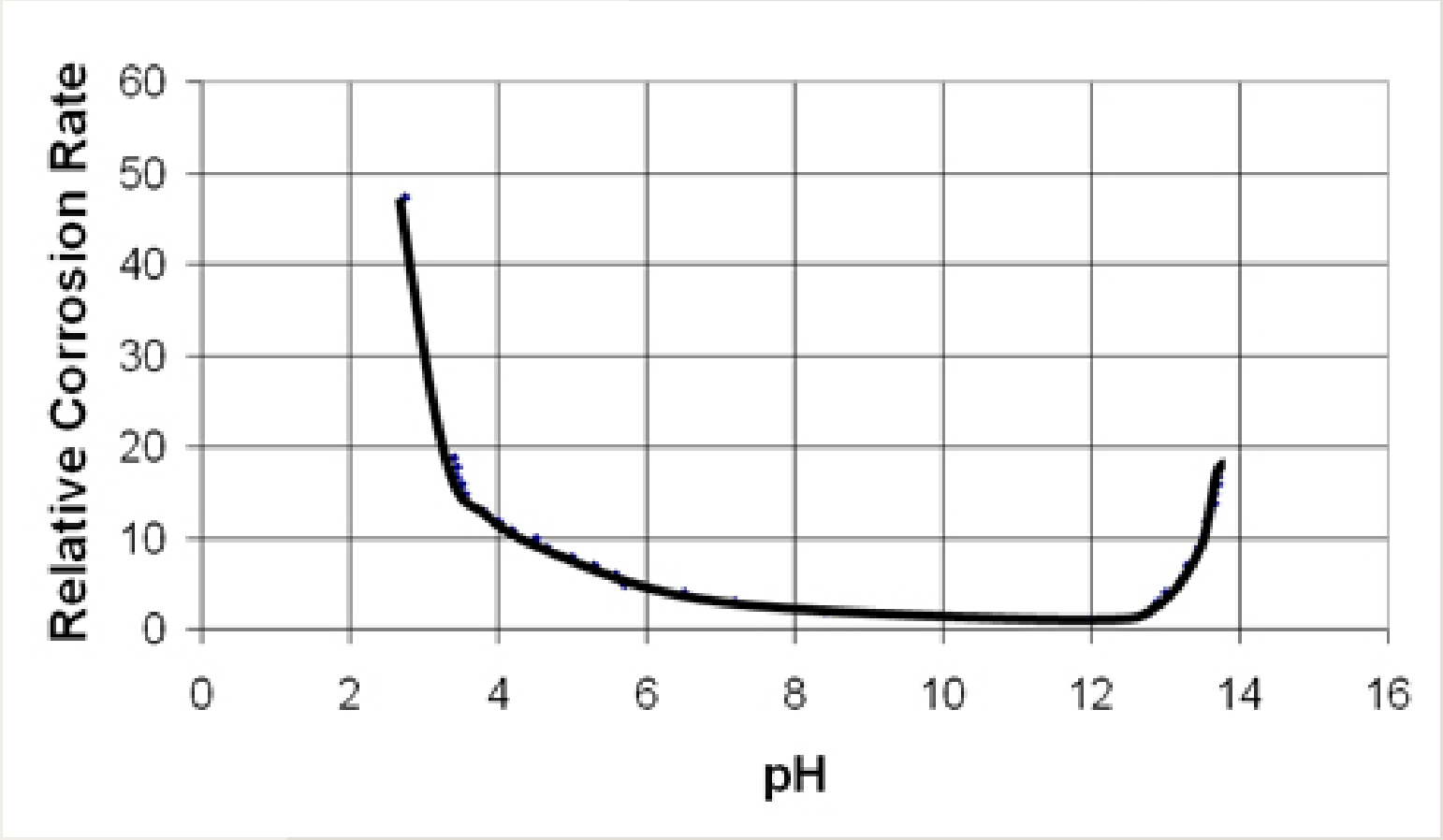
Environmental Performance

- Atmospheric
- Liquid (Chemicals, Fresh H_2O, Salt H_2O)
- Soil
- High Temperature
- Low Temperature
- Concrete

Atmospheric: Service Life of HDG



Liquid: Effect of pH on HDG steel



Performance in Soil

- **> 200 different soil types**
- **Complex corrosion kinetics in soil**
- **Variables include:**
  - Porosity
  - Resistivity
  - Organic material
  - Moisture content
  - pH
  - Temperature

Performance in Various Temps

- **High Temperature**
  - < 392 F (200 C)
- **Low Temperature**
  - > -75 F (-60 C)

Concrete: Rebar Corrosion

Staining

Cracking

Spalling

Complete Failure

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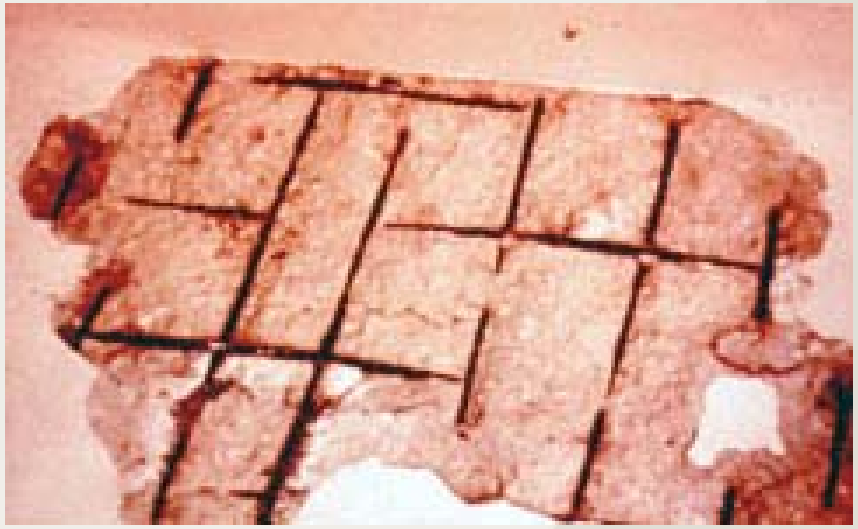
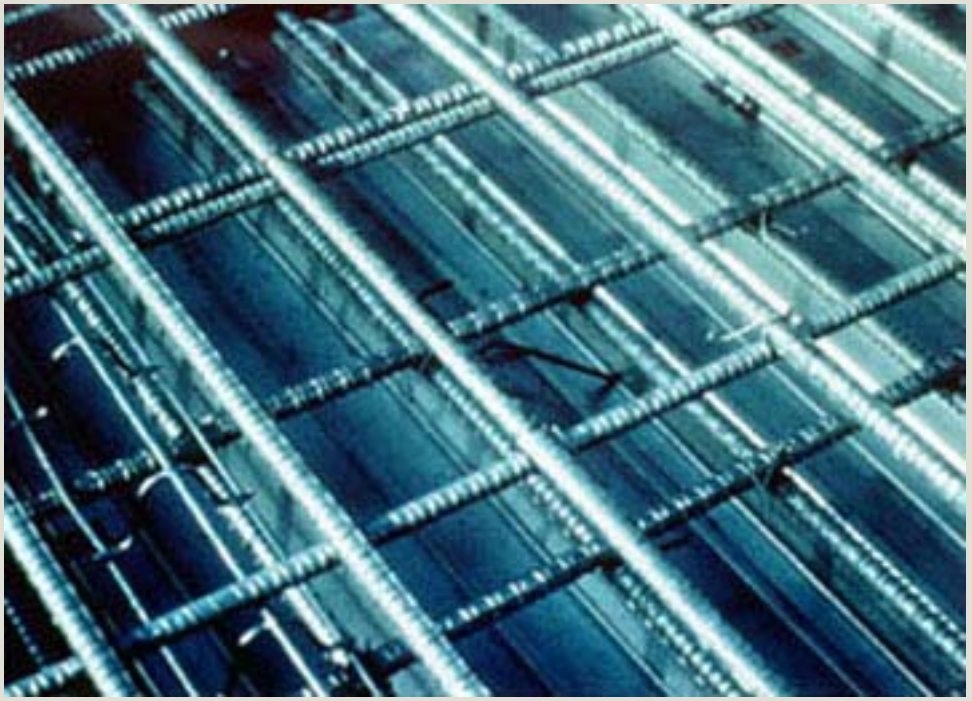
Concrete: Galvanized Rebar



Unprotected Rebar



Galvanized Rebar

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Zinc is Natural

Air

Soil

Water

Features of HDG Coatings

- Zinc-iron intermetallic layers
- Harder than the substrate steel
- Zinc patina
- Barrier protection
- Cathodic protection
- Metallurgical bond to the substrate steel
- Paintable
- Edge and corner protection
- Zinc is a natural and healthy metal

Benefits of HDG Coatings

- Maintenance-free for 50 – 100 years in most atmospheric environments
- Long term performance in soils, water, and chemical environments
- No touch-up required
- High & Low temperature performance
- Application independent of weather
- 100% recyclable

Dry Bridge Road Bridge

Date Galvanized
1999

Sector
Bridge & Highway

Environment
Rural

Location
Alexander, NY

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Harrisburg Airport Transportation Facility

Date Galvanized
2004

Sector
Building & Architecture

Environment
Urban

Location
Harrisburg, PA

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AES-PR Total Energy Power Plant

Date Galvanized
2002

Sector
Electrical, Utility & Communication

Environment
Industrial

Location
San Juan, Puerto Rico

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Leprino Foods

Date Galvanized
2002

Sector
Food & Agriculture

Environment
Rural

Location
Waverly , NY

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Aspinwall Water Treatment Plant

Date Galvanized
2001

Sector
Water & Marine

Environment
Industrial

Location
Pittsburgh, PA

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