Corrosion Protection

Basic corrosion theory and protection methods

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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

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

Conventional Current

Electrolyte

Cathode

Anode

Electrons

Electrons

External Circuit

Return Current Path
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

Same thickness at corner
Influencers of Coating Development

- Steel Surface Conditions
- Steel Chemistry
  - Silicon
  - Phosphorous
The Sandelin Curve
Coating Appearance

- Newly Galvanized
  - No Spangle

- Newly Galvanized
  - Highly Spangle

- Newly Installed
  - Shiny & Dull Coating

*Uniiversity Tool Kit*
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

1. Free flowing air
   \[ \text{O}_2 \]

2. Moisture from rain (dew)
   \[ \text{H}_2\text{O} \]

3. Free flowing air
   \[ \text{O}_2 + \text{CO}_2 \]

Zinc Oxide
\[ \text{ZnO} \]

Zinc Hydroxide
\[ \text{Zn(OH)}_2 \]

Zinc Carbonate
\[ 2\text{ZnCO}_3 \cdot \text{Zn(OH)}_2 \]

Fully developed patina
Environmental Performance

- Atmospheric
- Liquid (Chemicals, Fresh H₂O, Salt H₂O)
- Soil
- High Temperature
- Low Temperature
- Concrete
Atmospheric: Service Life of HDG

**Average Thickness of Zinc (mils)**

*Service life is defined as the time to 5% rusting of the steel surface.*

1 mil = 25.4μm = 0.56oz/ft²
Liquid: Effect of pH on HDG steel

![Graph showing the effect of pH on relative corrosion rate.](image-url)
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)

*University Tool Kit*
Concrete: Rebar Corrosion

- Staining
- Cracking
- Spalling
- Complete Failure
Concrete: Galvanized Rebar

Unprotected Rebar

Galvanized Rebar
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
Harrisburg Airport Transportation Facility

Date Galvanized: 2004

Sector: Building & Architecture

Environment: Urban

Location: Harrisburg, PA
AES-PR Total Energy Power Plant

Date Galvanized
2002

Sector
Electrical, Utility & Communication

Environment
Industrial

Location
San Juan, Puerto Rico
Leprino Foods

Date Galvanized
2002

Sector
Food & Agriculture

Environment
Rural

Location
Waverly, NY
Aspinwall Water Treatment Plant

Date Galvanized
2001

Sector
Water & Marine

Environment
Industrial

Location
Pittsburgh, PA