Fundamentals of Corrosion

Period 2

Basic Corrosion Course
2017
FUNDAMENTALS OF CORROSION

CHAPTER OBJECTIVES

- What is Corrosion?
- Basic Corrosion Cell
- Rates of Corrosion
- Causes of Corrosion
- Types of Corrosion
Cost of corrosion

- 2002 US Federal Highway Administration Report Estimates Direct Annual Cost of Corrosion in the United States at $276 Billion Per Year or 3.1% of GDP

- As of June of 2013 that number has climbed to over an estimated $500 Billion for the direct annual cost of corrosion.

- According to a study by the World Corrosion Organization, the annual cost of corrosion across the world is $2.2 Trillion.
Cost of corrosion-Sissonville, WV
Cost of Corrosion-Sissonville, WV
Cost of Corrosion-Sessionville, WV
What is Corrosion?

• Corrosion is the degradation of a material due to a reaction with its environment

• Simply stated, corrosion is a materials tendency to want to return to its natural state. In the case of steel, iron oxide or rust.

• Corrosion is an electrochemical reaction involving metals, chemicals and water
Definitions

• Corrosion cells are composed of the following four basic elements:

• Anode
  The portion of a metal surface that is corroded from which current leaves the metal to enter the solution. The point where Oxidation occurs

• Cathode
  The portion of a metal surface from which current leaves the electrolyte and returns to metal. The point where Reduction occurs

• Electrolyte
  A solution containing ions that is capable of conducting electricity

• Metallic Path
  Metallic connection between the anode and cathode
Basic Corrosion Cell

Anode

Cathode

Electrolyte

Metallc Path
Corrosion Cell

Fe → Fe^{++} + 2e^- (Oxidation at Anode)

2H^{+} + 2e^- → 2H (Reduction at Cathode)

H_2O → H^+ + (OH)^- (Ionized Electrolyte)
Conventional Current FLOW

Electron Flow-From the anode to the cathode in the metallic path

Conventional current flow-From the anode to the cathode in the electrolyte
Active Corrosion Cell

\[
\begin{align*}
H_2O & \rightleftharpoons H^+ + (OH)^- \text{ (Ionized Electrolyte)} \\
Fe & \rightarrow Fe^{++} + 2e^- \text{ (Oxidation at Anode)} \quad 2H^+ + 2e^- \rightarrow 2H \quad \text{(Reduction at Cathode)}
\end{align*}
\]
Electrical Quantities in the Basic Cell

• Three Electrical Quantities (Chapter 1) – Ohm’s Law  
  I= Current Flow  E= Driving Force  R= Resistance

• Corrosion reactions take place because of a voltage difference between the anode and cathode
  • This is called the “Driving Voltage” of the cell
  • Measured in DC volts or Millivolts
  • Potential Difference

• Corrosion reactions are not plating reactions
  • There is no migration of ions from the anode to the cathode

• Anodes and cathodes are frequently located at different spots on the same structure
Potential Difference
Potential Difference
Potential Difference
Potential Difference
Rate of Corrosion

• Polarization
  – Retardation in the rate of corrosion or current flow
  – Caused by a reduction in voltage difference or an increase in resistance between anode and cathode

• Electrolyte Resistivity
  – Structures placed in high resistivity electrolytes tend to corrode slower than low resistivity environments

• Voltage Difference between Anode and Cathode
  – The greater the voltage difference between two metals, the greater the rate of corrosion
Rate of Corrosion (cont.d)

• Anode / Cathode Ratio
  – The relative area between the anode and the cathode greatly affects the rate at which the anode corrodes

• Effect of the Metal Itself
  – Different metals corrode at different rates
  – The rate of corrosion is expressed by Faraday’s Law
    \[ W = K \times I \times T \] (\(W=\)weight loss, \(K=\)electrical chemical equivalent in pounds per ampere per year, \(I=\)Corrosion current in amperes, \(T=\)time in years)

• Passivation of the Metal Surface
  – The ability of a metal to produce a protective film (oxide) enhances its ability to reduce the corrosion process
  – Pitting corrosion will often occur at the point where film breakdown is sustained
Causes of Corrosion

- **Natural Occurring Corrosion** (Corrosion caused by a natural reaction between metal and its environment)
  - Dissimilar Metals
  - Dissimilar Surfaces
  - Dissimilar Electrolytes
  - Oxygen Concentration
  - Stress Corrosion
  - Erosion and Cavitation
  - Graphitization
  - Stray Current Corrosion
Causes of Corrosion

• Dissimilar Metals
  – Copper vs. Steel Services
  – Old vs. New Pipe
  – Steel Nails in Aluminum Gutter
  – Brass Valve in Steel Water Line
**FIGURE 4**

**PRACTICAL GALVANIC SERIES**

<table>
<thead>
<tr>
<th>Metal</th>
<th>Volts&lt;sup&gt;(1)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercially pure magnesium</td>
<td>-1.75</td>
</tr>
<tr>
<td>Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)</td>
<td>-1.6</td>
</tr>
<tr>
<td>Zinc</td>
<td>-1.1</td>
</tr>
<tr>
<td>Aluminum alloy (5% Zn)</td>
<td>-1.05</td>
</tr>
<tr>
<td>Commercially pure aluminum</td>
<td>-0.8</td>
</tr>
<tr>
<td>Mild steel (Clean and shiny)</td>
<td>-0.5 to -0.8</td>
</tr>
<tr>
<td>Mild steel (rusted)</td>
<td>-0.2 to -0.5</td>
</tr>
<tr>
<td>Cast iron (not graphitized)</td>
<td>-0.5</td>
</tr>
<tr>
<td>Lead</td>
<td>-0.5</td>
</tr>
<tr>
<td>Mild steel in concrete</td>
<td>-0.2</td>
</tr>
<tr>
<td>Copper, brass, bronze</td>
<td>-0.2</td>
</tr>
<tr>
<td>High silicon cast iron</td>
<td>-0.2</td>
</tr>
<tr>
<td>Mill scale on steel</td>
<td>-0.2</td>
</tr>
<tr>
<td>Carbon graphite, coke</td>
<td>+0.3</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> Typical potentials measured between metal (when immersed in neutral soils or waters) and a copper-copper sulfate reference cell contacting the adjacent soil or water.
Dissimilar Metals

Figure 5
DISSIMILAR METAL CORROSION

Figure 6
DISSIMILAR METAL CORROSION
Dissimilar Metals

Figure 7
DISSIMILAR METAL CORROSION

Figure 8
DISSIMILAR METAL CORROSION
Dissimilar Metals
Dissimilar Metals
Causes of Corrosion (Cont.)

• Dissimilar Surfaces
  – Threads
  – Scratches and Gouges (wrench marks)
  – Inclusions and hard spots
  – Cold Working (pipe bends)
Dissimilar Surfaces

Figure 11
CORROSION CAUSED BY DISSIMILARITY OF SURFACE CONDITIONS
Dissimilar Surfaces
Causes of Corrosion (Cont.)

- Dissimilar Electrolytes
  - Pasture vs. Plowed Field
  - Clay vs. Sand Backfill
  - Bottom of Pipe vs. Top
  - Road Crossings
  - Crevices
  - Solid Deposits (internal)
  - Solid Deposits (external)
Dissimilar Electrolyte

Figure 13

CORROSION CAUSED BY DISSIMILAR SOILS
DISSIMILAR ELECTROLYTE

Figure 14
CORROSION CAUSED BY MIXTURE OF DIFFERENT SOILS
Causes of Corrosion (Cont.)

• Oxygen Concentration Cells
  • Difference in oxygen concentration around a structure
  • Anodic area develops in low oxygen concentration
  • Often causes leaks under bolt heads and washers, and in cracks and crevices
  • Specially severe on stainless steel and aluminum
Oxygen Concentration

Figure 15
CORROSION CAUSED BY DIFFERENTIAL AERATION OF SOIL
Causes of Corrosion (Cont.)

• Stress Corrosion
  
  • Stress Corrosion Cracking (SCC)
    
    – Tensile Stress, Environment, Material
    
    – The more highly stressed areas become anodic to the less stressed areas
    
    – It becomes a problem with high strength metals and severe failures can occur
Stress Corrosion

Lower Stressed Area (Cathode)  Lower Stressed Area (Cathode)

Higher Stressed Area (Anode)

Pipe

Coupling

Figure 16
STRESS CORROSION
Causes of Corrosion (Cont.)

• Microbiologically Induced (MIC)
  – Bacteria growth causes a change in the environment

• Erosion and Cavitation
  – Specialized form of corrosion caused by turbulence and excessive fluid velocity

• Graphitization
  – Corrosion of iron causes a loss of iron constituent, leaving behind the graphite and product of corrosion
Causes of Corrosion (Cont.)

- Stray Current Corrosion
  - Current comes from some source external to the structure
  - Can be devastating due to the large current involved

- Two Types of Stray Current Corrosion
  - Static (Steady State)
    - Foreign Pipeline
    - AC Interference

  - Dynamic (Variable Current)
    - Light Rail
    - Telluric
    - AC Interference
Dynamic Current

Figure 17

Stray Current from Rapid Transit
Static Current

![Static Current Diagram]

Figure 19

CATHODIC PROTECTION INTERFERENCE
Static Current

Bipolar Operation
No Current in the Earth

Stray Current
Monopolar Operation
Showing Earth Return

Figure 20
HIGH VOLTAGE DC TRANSMISSION LINE
Review

• What is the definition of corrosion?
• What kind of reaction is corrosion?
• What are the four basic elements of a corrosion cell?
• What are some causes corrosion?
• From the galvanic series, what would be the best metal choice for an anode?
Summary

• Learned about Basic Corrosion Cells

• Discussed the Rates of Corrosion

• Reviewed the Galvanic Series

• Identified the different Causes of Corrosion
• Questions?

• Comments?