Corrosion & Associated Degradation

Objectives

- Corrosion process
- Environmental factors
- Common forms of corrosion
- Methods of corrosion control and prevention

Metal Corrosion

- "the destruction of a material by chemical or electrochemical reaction to its environment"
- typically a transfer of electrons from one metal to another through an Oxidation-Reduction Reaction.

Oxidation - Reduction Reduction

- Anodic metal gives up electrons (oxidation)

$$Fe \rightarrow Fe^{+2} + 2e^{-}$$

$$Al \rightarrow Al^{+3} + 3e^{-}$$

- Cathodic metal accepts electrons (reduction)

$$Cu^{2+} + 2e^{-} \rightarrow Cu$$

- Or gases accept electrons (reduction)

$$2H^{+} + 2e^{-} \rightarrow H_2(gas)$$

Corrosion Mechanism

- Cathodic cell
  - discussion of emf
- galvanic series
- intergranular corrosion
- oxidation-reduction of iron
- salt effects

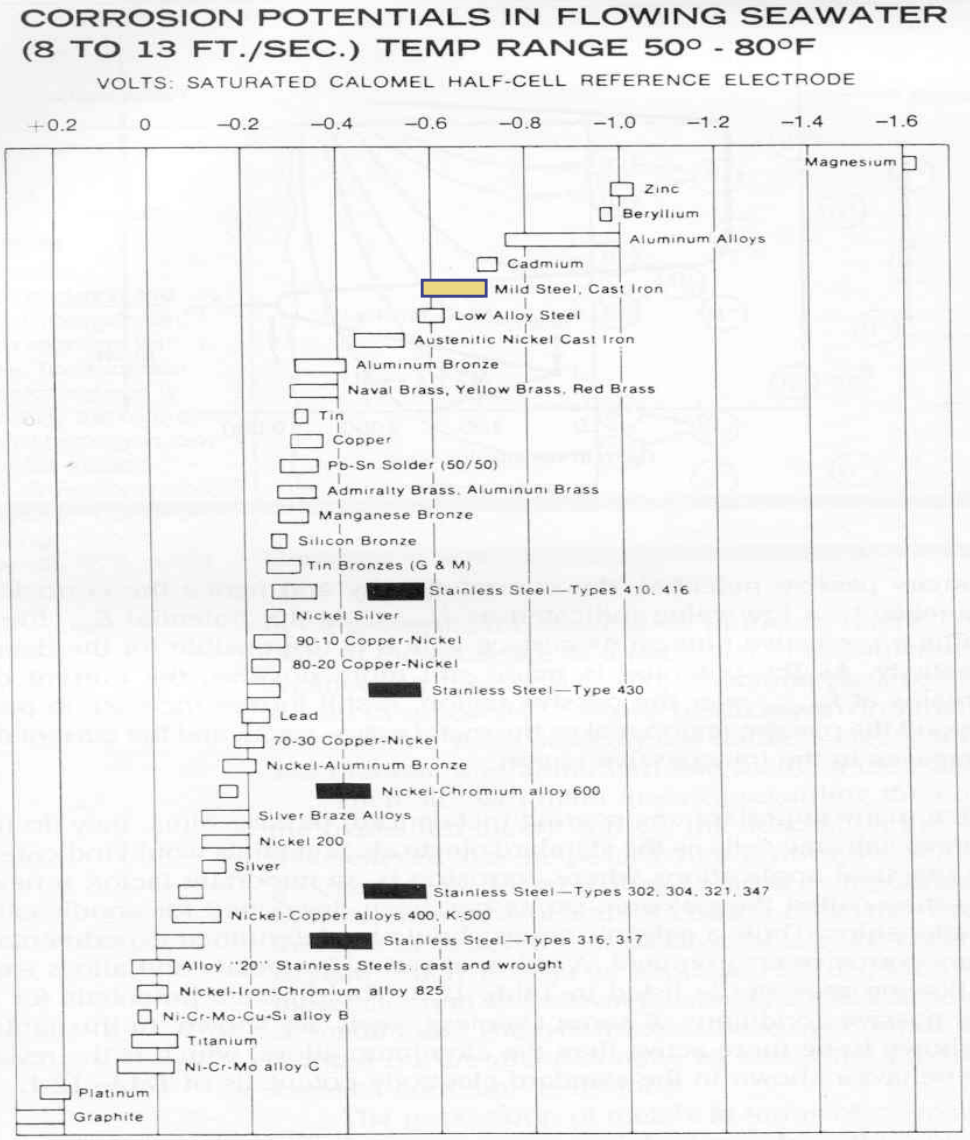
Slides on Impact of Corrosion

- Aluminum corrosion
- Pitting
- Crevice corrosion
- Contaminants
- Environments

Basics of Corrosion

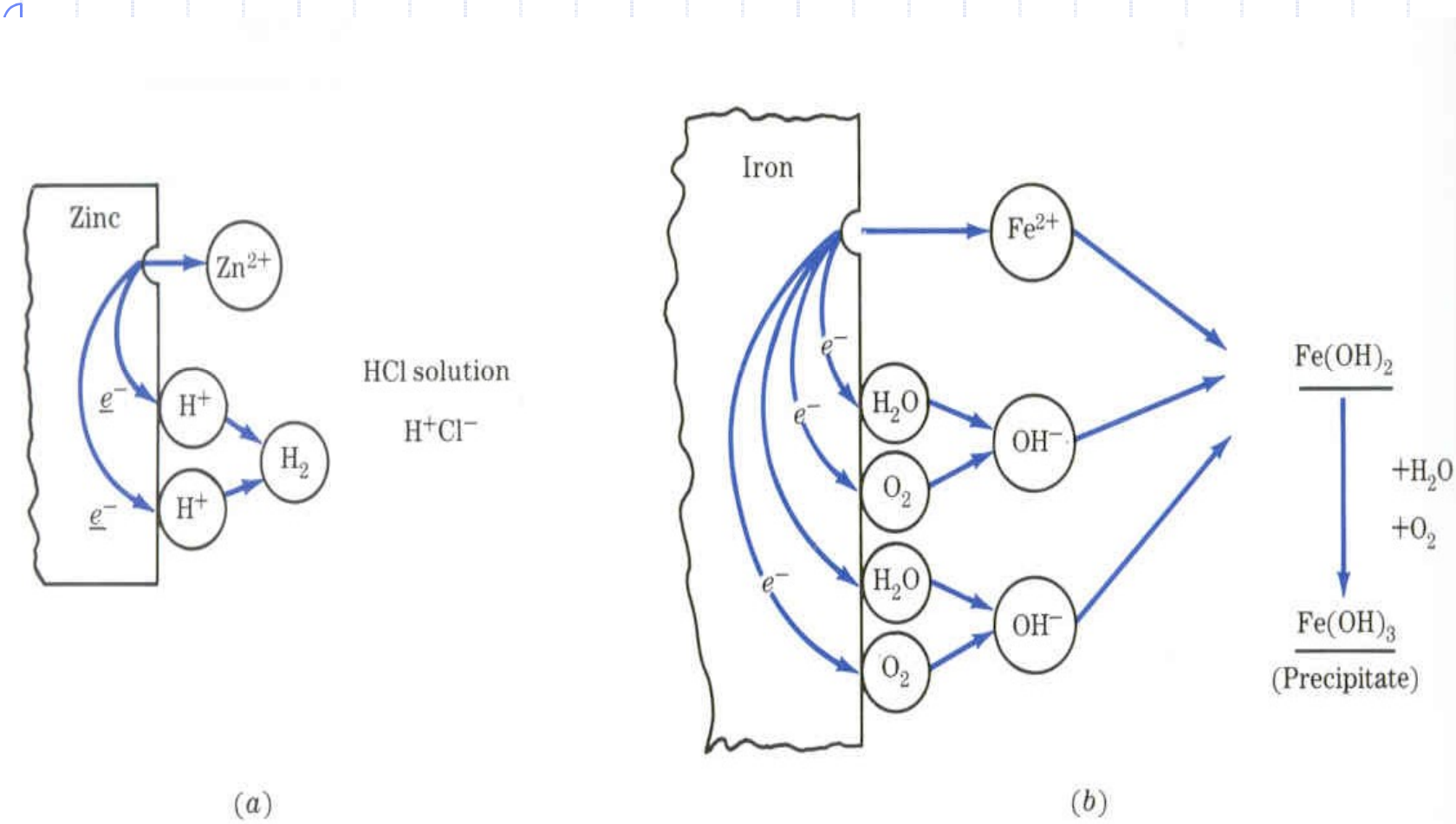
- EMF series is a numeric rating of potential under ideal conditions
- Galvanic Series is a practical listing
- Galvanic Protection

TABLE 12.3 Galvanic Series in Flowing Seawater



Alloys are listed in the order of the potential they exhibit in flowing seawater. Certain alloys indicated by the symbol: ▬ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near −0.5 volts.

Source: Courtesy of the LaQue Center for Corrosion Technology, Inc.


Zinc
Zn^{2+}
e^-
H^+
H_2
e^-
H^+
HCl solution
H^+Cl^-
(a)
Iron
Fe^{2+}
e^-
H_2O
OH^-
e^-
O_2
H_2O
OH^-
e^-
O_2
$Fe(OH)_2$
$+H_2O$
$+O_2$
$Fe(OH)_3$
(Precipitate)
(b)

Steel Corrosion

Initial Oxidation Reaction

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2$$

Secondary Oxidation Reaction

$$2Fe(OH)_2 + \frac{1}{2}O_2 + H_2O \rightarrow 2Fe(OH)_3$$

Rust

TABLE 12.1 Standard Electrode Potentials at 25°C*

	Oxidation (corrosion) reaction	Electrode potential, $E°$ (volts vs. standard hydrogen electrode)
More cathodic (less tendency to corrode) ↑	$Au \rightarrow Au^{3+} + 3e^-$	+1.498
	$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$	+1.229
	$Pt \rightarrow Pt^{2+} + 2e^-$	+1.200
	$Ag \rightarrow Ag^+ + e^-$	+0.799
	$2Hg \rightarrow Hg_2^{2+} + 2e^-$	+0.788
	$Fe^{2+} \rightarrow Fe^{3+} + e^-$	+0.771
	$4(OH)^- \rightarrow O_2 + 2H_2O + 4e^-$	+0.401
	$Cu \rightarrow Cu^{2+} + 2e^-$	+0.337
	$Sn^{2+} \rightarrow Sn^{4+} + 2e^-$	+0.150
	$H_2 \rightarrow 2H^+ + 2e^-$	0.000
More anodic (greater tendency to corrode) ↓	$Pb \rightarrow Pb^{2+} + 2e^-$	−0.126
	$Sn \rightarrow Sn^{2+} + 2e^-$	−0.136
	$Ni \rightarrow Ni^{2+} + 2e^-$	−0.250
	$Co \rightarrow Co^{2+} + 2e^-$	−0.277
	$Cd \rightarrow Cd^{2+} + 2e^-$	−0.403
	$Fe \rightarrow Fe^{2+} + 2e^-$	−0.440
	$Cr \rightarrow Cr^{3+} + 3e^-$	−0.744
	$Zn \rightarrow Zn^{2+} + 2e^-$	−0.763
	$Al \rightarrow Al^{3+} + 3e^-$	−1.662
	$Mg \rightarrow Mg^{2+} + 2e^-$	−2.363
	$Na \rightarrow Na^+ + e^-$	−2.714

*Reactions are written as anodic half-cells. The more negative the half-cell reaction, the more anodic the reaction is and the greater the tendency for corrosion or oxidation to occur.

Corrosion potential calculation

- Reduction Reaction must have higher potential than the oxidation reaction or they will not form a cathodic cell

$$Fe^{+2} + 2e^{-} \rightarrow Fe \qquad \textit{-0.440 V}$$

$$Zn^{+2} + 2e^{-} \rightarrow Zn \qquad \textit{-0.763 V}$$

$$\Delta V = -.440 - (-.763) = +0.323V$$

Relative measure of corrosion

Acceleration of Corrosion

- Physical Characteristics
  - exposed area (less, increases corrosion rate)
  - time of exposure (more time, more corrosion)
- Environmental Characteristics
  - acidic environment
  - sulfur gas environment
  - temperature (high temps, more corrosion)
  - moisture (oxygenated moisture)

Passivation

- A protective film in oxidizing atmospheres
  - chromium,nickel, titanium, aluminum
- Metal oxide layer adheres to parent metal
  - barrier against further damage
  - self-healing if scratched
- Sensitive to environmental conditions
  - passivated metal may have high corrosion rates

Forms of Corrosion

- Uniform corrosion of a single metal
  - usually an electrochemical reaction at granular level
  - relatively slow and predictable
  - rusting of exposed steel, tarnished silver
  - easily corrected with coatings and regular maintenance

Forms of Corrosion

- Galvanic Corrosion
  - 2 dissimilar metals, electrolyte, electrical connection and oxygen
- Pitting Corrosion
  - Localized corrosion forming holes or indentations
  - Difficult to initially detect

Forms of Corrosion

- Crevice Corrosion
  - narrow crevice filled with ionized solution
  - Oxygen-rich on the outside, oxygen-poor on the inside
  - metals oxidize with salt anions $FeCl_2$ and pH rises in cathodic zone
  - H^+ may destroy passivity

Forms of Corrosion

- Intergranular Corrosion
  - corrosion along grain boundaries at microscopic level
  - stainless steels and heat treated high-strength steels
  - carbides precipitate along grain boundaries leaving these areas with no alloyed Chromium
  - Welds can have this same depletion effect

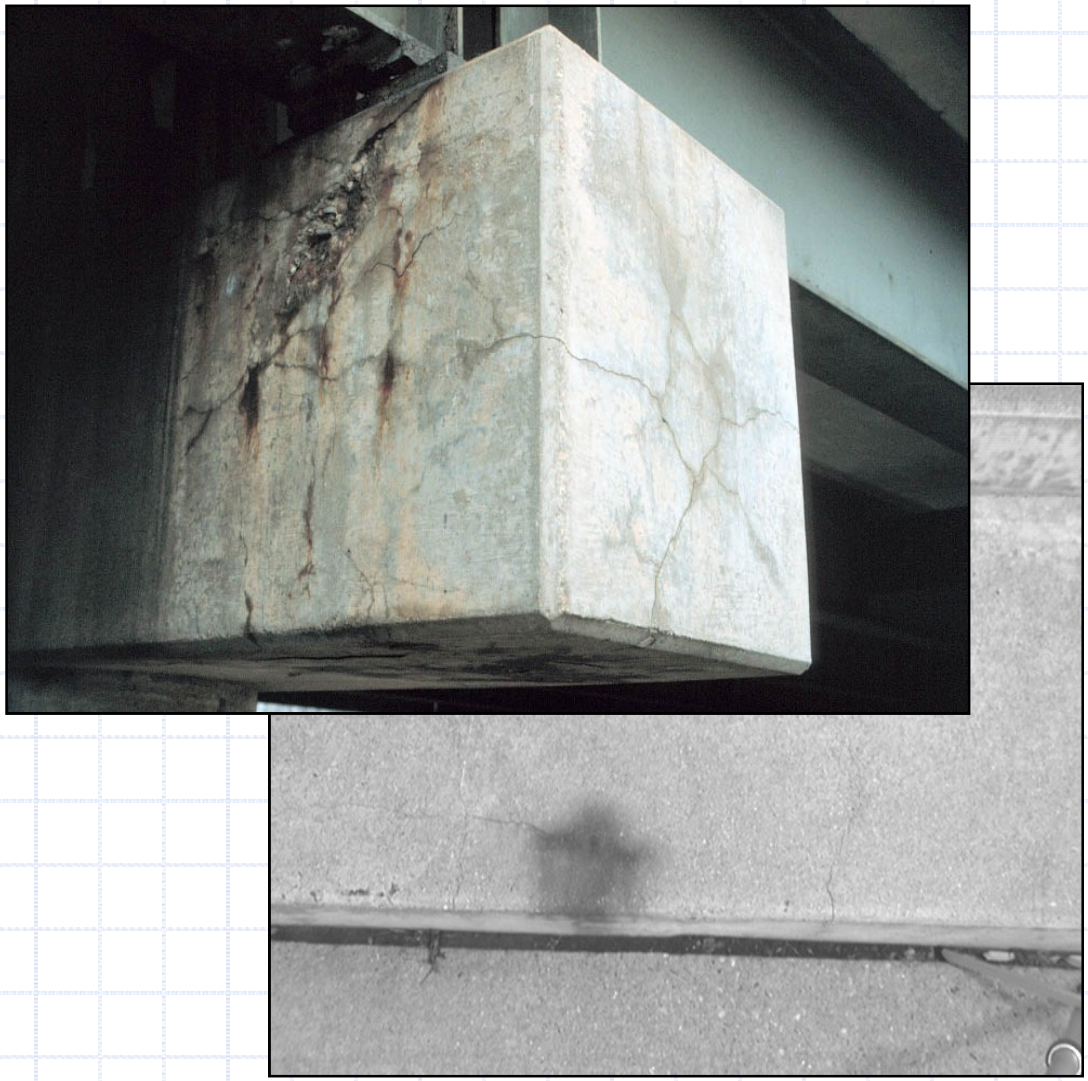
Forms of Corrosion

- Cavitation and Erosion in Pipe
  - particulate matter
  - turbulent flow
  - abrades away the corrosion product
  - abrasion of zinc coatings

Forms of Corrosion

- Stress Corrosion Cracking
  - tensile stress and corrosive environments
  - cracks are initiated at corrosion areas
  - tensile stresses propagate the crack
  - corrosion further deteriorate crack
  - etc.....

Reinforcement Corrosion

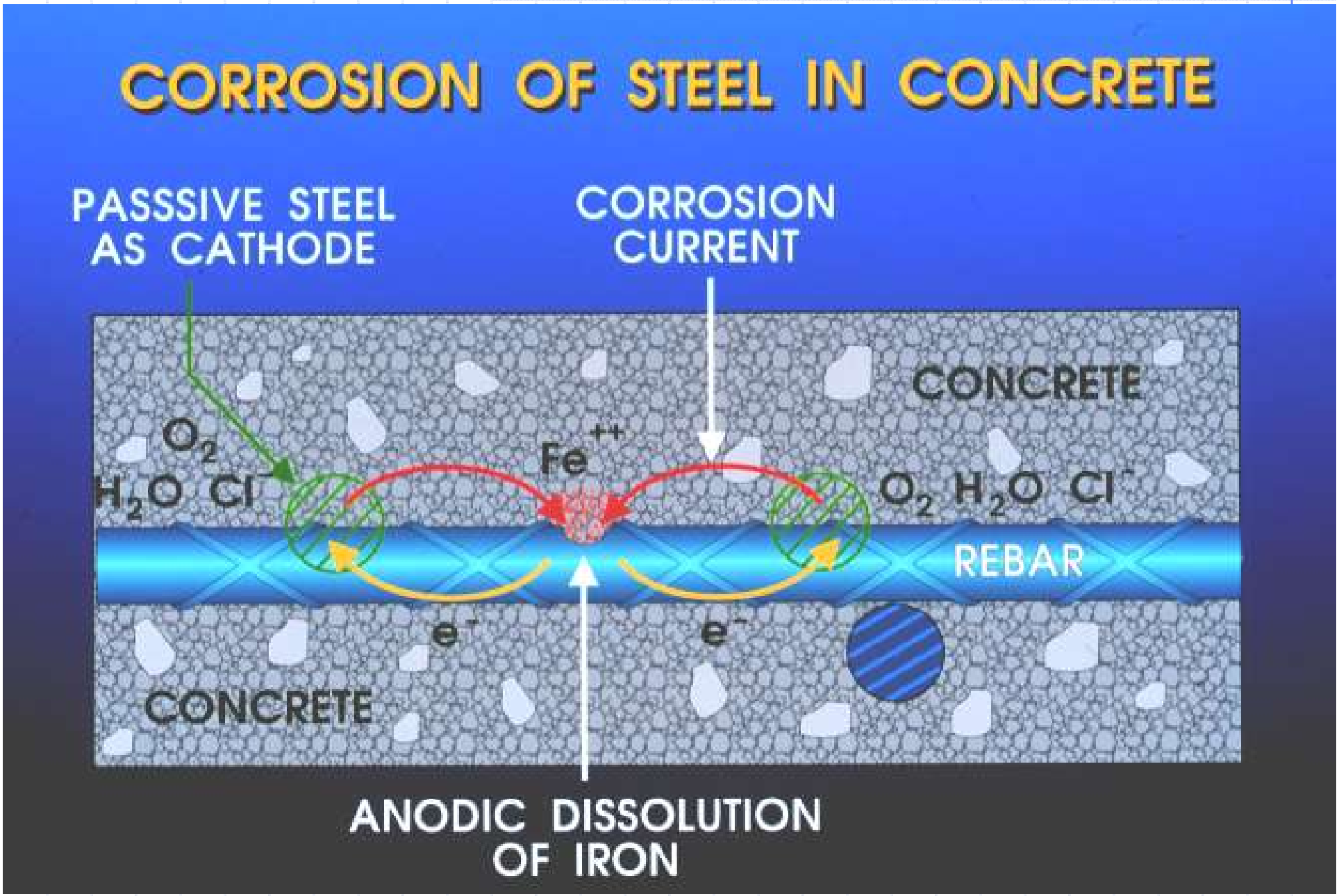


Corrosion Products

- $Fe + 2OH = Fe(OH)_2$
- Oxidation of $Fe(OH)_2$
- $Fe(OH)_3$ (rust)
- Passivity barrier breaks down
- Presence of Oxygen
- Moisture

Corrosion of Metals in Concrete Reinforcing Steel & Prestressing Steel

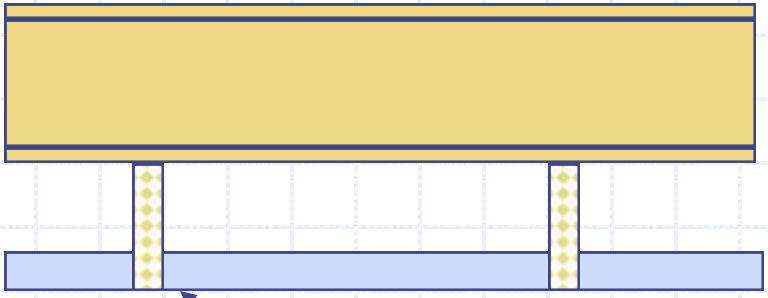
- Concrete is Normally Highly Alkaline
  - Protects Steel from Rusting if Properly Embedded
- If Corrosion Occurs, the Reaction Products are Greater in Volume Than the Original Steel
- Corrosion Initiation and Rate Depends On
  - Amount of Concrete Cover, Quality of Concrete
  - Details of Construction, & Exposure to Chlorides


CORROSION OF STEEL IN CONCRETE
PASSSIVE STEEL AS CATHODE
CORROSION CURRENT
CONCRETE
O_2
H_2O Cl^-
Fe^{++}
O_2 H_2O Cl^-
REBAR
e^-
e^-
CONCRETE
ANODIC DISSOLUTION OF IRON

Avoiding Corrosive Situations

- Choose couple metals close on the galvanic series
- Use large anode, and small cathode areas
- Electrically insulate dissimilar metals
- Connect a more anodic metal to the system
- Avoid turbulent flow and impingements in pipe systems

Examples of Corrosion in CE



condensation on the bottom of cold water pipe

- Steel strapping or iron nails with copper pipe is ok, but they may rust with time.
- Never use Copper strapping or attachments with steel pipe, steel pipe will corrode

Corrosion Prevention

- Coatings
  - Barrier films
  - Inhibitive Pigments
  - Sacrificial treatments
  - Paint
- Active Cathodic Protection