Basics of Corrosion
Performance Metals

- Sacrificial anode manufacturer
- Specialize in aluminum alloy anodes
- All products made in the USA (Berks county, PA)
- ISO9001/2001 Certified Quality System
- Also traditional die-casting company supplying aluminum and zinc die-castings to wide range of industries
Atoms consist of:

- **Nucleus:**
  - Protons
  - Neutrons

- **Electrons**

- **Atom is electrically balanced** — equal electrons and protons

26 Protons, 26 Neutrons - 26 Electrons
Metals Can Dissolve

- Atoms of metal dissolve into water
- Give up electrons to form positively charged ions
- Leave electrons behind
- Gives metal a negative charge
Corrosion

- Each metal generates different voltage
- Tendency to corrode depends on position on GALVANIC SERIES
- Lower the voltage (more negative) – the more active – more likely to corrode.
Simple Electrochemical Corrosion

- Electrochemical process of deterioration of metal
- Reverting to oxide
- Positive (Cathodic) and negative (Anodic) areas form on surface
- Metal dissolves from anodic areas
- Circuit is competed by ions traveling between anode and cathode areas
- Relatively slow process
Galvanic Corrosion

• What happens when two dissimilar metals are in contact in water?
Galvanic Corrosion

Whenever two metals are immersed in a liquid they form a battery and one starts to corrode:

![Diagram showing galvanic corrosion with a 0.3 Volt difference between cathode and anode]

- **COPPER**
- **STEEL**

*e.g. The steel corrodes to protect the copper! This is a much faster process*
Solution - Sacrificial Anodes

- The solution:
- Add a more "active" material
- Sacrificial Anode
- Protects the steel and copper

(Invented by Sir Humphrey Davy – 1824)
Solution #2 – Impress Current System

- Same principal:
- Instead of anode a dc power source (battery) provides the protective voltage
What is Electrolysis?

• Process by which water is broken down into Hydrogen and Water by the application of an a direct current
  – At anode: \(2H_2O \rightarrow 4e^- + 4H^+ + O_2 \text{ (gas)}\)
  – At cathode: \(4H_2O + 4e^- \rightarrow 2H_2 \text{ (gas)} + 4OH^-\)
  – In the electrolyte: \(4H^+ + 4OH^- \rightarrow 4H_2O\)
  – Add together: \(2H_2O \rightarrow 2H_2 \text{ (gas)} + O_2 \text{ (gas)}\)
Under and Overprotection

- To protect a metal it’s potential must be reduced by 250mV (after anode is added)
- Less means some anodic corrosion is still occurring
- More can increase anode usage and/or cause damage to aluminum or wood components
- Aluminum is “amphoteric”
  - Corrosion occurs if voltage reduced below –1200mV
  - Production of Hydrogen bubbles can lift paint and Chlorine gas can attack aluminum
- Wood can be damaged by corrosion products (OH- ions) – alkalis attack lignin
Historically, zinc has been used, because it works as an anode in its natural state.

However there is a better material – Aluminum/Indium alloy

Aluminum anode alloy gives bigger “driving” voltage. E.g. when protecting aluminum - (.35V) compared with (.28V) for zinc
Sacrificial Anode Materials

Magnesium is the most active – Why not use that?

Danger of “over-protecting” aluminum

Aluminum is “amphoteric” and if driven below -1.2V will corrode due to formation of alkalis
Advantages of Aluminum

- More active than zinc –1.1V vs. 1.03V
- Longer life – Extra 25% - 30% life compared with zinc. 5 times magnesium!
  - Zinc capacity 368 AH/lb
  - Aluminum 1150 AH/lb
- But density:
  - Zinc .25 lb/cu in
  - Aluminum .10 lb/cu in
- Relative life AH/cu in
  - Zinc 92
  - Aluminum 115 (+25%)
Advantages of Aluminum

• Suitable for salt and freshwater
  – In freshwater zinc coats over with zinc hydroxide and stops working after approx. two months
  – This can occur in saltwater too – particularly when polluted
  – Aluminum anodes stay active

• Remains active if exposed to air
  – If zinc anodes are removed from water they coat over
  – Aluminum anodes will reactivate when re-immersed
Advantages of Aluminum

- Environmentally friendly (Zinc causes pollution)

- Density 40% of that of zinc
Anode Dos and Don’ts

• **Do:**
  – Change when 50% corroded
  – Make sure of good electrical contact
  – Replace annually (especially if zinc)

• **Don’t**
  – Do not paint
  – Do not mix anode types – aluminum will protect zinc
  – Do not use zinc anodes to protect aluminum components
  – Do not use magnesium anodes on aluminum in salt water
Factors Affecting Corrosion

- Conductivity
  - salt vs. fresh water
  - Pollution (increases conductivity)
- Presence of oxygen
- Oxygen Depletion (Stainless Steel)
- Flow rate
- Temperature
- Stress
Factors Affecting Corrosion - Conductivity

- Corrosion increases with conductivity
- Very pure water almost non-conducting
- Salt water 10 times as conductive as river water
- Due to presence of Na+ and Cl- ions (salt)
  - 30 feet diameter salt water pipe equivalent to #10 copper conductor (.102")
- Pollutants contribute ions and increase conductivity (e.g. acid rain)
Factors Affecting Corrosion – Presence of Oxygen

- Oxygen provides OH- ions
  \[ \text{O}_2 + 2\text{H}_2\text{O} + 4\text{ e-} \rightarrow 4(\text{OH-}) \]
- These ions provide a necessary part of electrolytic current flow
- OH- ions combine with metal ions to form Hydroxides
- Hydroxides can coat metal and stifle corrosion – Copper, Zinc (Not Steel)
Factors Affecting Corrosion – Oxygen Depletion

- Stainless Steel - Exception to rule!
- Stainless contains Nickel and Chromium
- Forms thin protective oxide layer ("passive")
- Needs continual supply of dissolved oxygen
- Film is fragile in presence of Chlorine Ions (Salt water)
Factors Affecting Corrosion
– Oxygen Depletion

- Under seals, strut bearings or barnacles (no oxygen) film breaks down – metal becomes “active” – pitting or crevice corrosion results
- Monel and Titanium can pit but much more corrosion resistant
Factors Affecting Corrosion – Flow Rate

- Flow rate can increase corrosion rate
- Copper alloys affected
  - Silicon Bronze
  - Manganese Bronze (in truth a Brass) more resistant (but susceptible to dezincification)
- Stainless Steel – Exception
  - flow contributes oxygen – forms oxide layer.
- Propeller tips can show corrosion
Factors Affecting Corrosion – Temperature

- Corrosion rate doubles for every 10 degree C (18 degree F) rise in temperature
Factors Affecting Corrosion – Stress

- Metal components under stress or with residual stress will corrode more rapidly
- Forged fasteners will often corrode around the head where most upsetting occurs
- Wrought metals are more prone than castings
- Welding can increase internal stresses
Dealloying

- Brass (Manganese Bronze) is an alloy of Copper and Zinc
- Zinc (if more than 15%) corrodes by galvanic action with Copper
- Aluminum Bronze – Aluminum Corrodes (if more than 10%)
Stray Current Corrosion (Electrolytic Corrosion)

- Stray Current (Electrolytic) Corrosion—caused by connection to a dc source of electricity
- Can be very serious—driving potential may be 12V compared with Galvanic potentials of 0.3V (36 times the rate)
Anode/Cathode Ratio of Areas

- **Anodic** areas need to be as large as possible compared to the **Cathodic** areas
  - Current flow is concentrated into surface area of anode
  - E.g. steel screw in copper will disappear quickly whereas in aluminum it will be protected
Anode/Cathode Ratio of Areas

- Consider a steel screw (anodic) holding a copper plate (cathodic)
Anode/Cathode Ratio of Areas
Anode/Cathode Ratio of Areas

- Now consider a bronze screw (cathodic) holding a steel plate (anodic)
Notes on Use of Aluminum

- Marine grades - 5000 or 6000 series
- Anodizing will improve appearance
- Note: is active on Galvanic scale so do NOT use bronze, brass or monel unless insulated
- Recommend use of 316 stainless fasteners etc.
- Beware of overprotection
Notes on Use of Brass

- Alloy of Copper and Zinc
- Suffers from de-zincification
- Use dezincification resistant brass, CZ132
- Must be cathodically protected
- Note: Manganese Bronze is a brass
Notes on Use of Bronze

• Alloy of Copper and Tin traditionally
• No Zinc or Nickel
• Extremely resistant to corrosion
• Best and most widely used – Silicon Bronze (1-3% silicon)
Notes on Use of Cupronickels

- Excellent material with excellent strength and corrosion resistance
- Good resistance to biofouling
- Cathodic protection not needed and will allow biofouling if used
Sacrificial Anode Wear
Patented Wear Indicator
U.S. Patent No. 6,932,891 B2

• Filed May 4, 2004
• Issued August 23, 2005
• Summary:
  – An apparatus for indicating when a predetermined portion of a sacrificial anode has been corroded comprises a detector embedded within the interior of the sacrificial anode initially at a predetermined distance from an exposed exterior surface of the sacrificial anode. The detector detects the absence of sacrificial anode material when the predetermined portion has corroded and generates a detection signal. A monitoring system communicates with the detector for receiving detection signals and generates an indicator signal when a detection signal is received. An indicator in communication with the monitoring system receives indicator signals and generates an alarm when an indicator signal is received.
Basic Patent - Original Anode

- Original Anode
- Wear Indicator
- Size when Replacement Required

Protected Metal
Basic Patent - Worn Anode

Indicator appears as a “Red Spot” in the surface of the anode.
Recreational Anode Example
Anode Examples

• Range

- MERCURY
- REDUCED CLEARANCE SHAFT
- RUDDER TRIM TAB
- VOLVO
- BOMBARDIER
- STREAMLINED SHAFT
- BENNETT
- YAMAHA
- HULL AND STRAINER
- POWER SERIES
Anode Examples

• Power Series
  – Finned for extra surface area.
Anode Examples

- Strap Anodes