CORROSION

PERFORMANCE METALS

Basics of Corrosion

PERFORMANCE METALS PRODUCTS

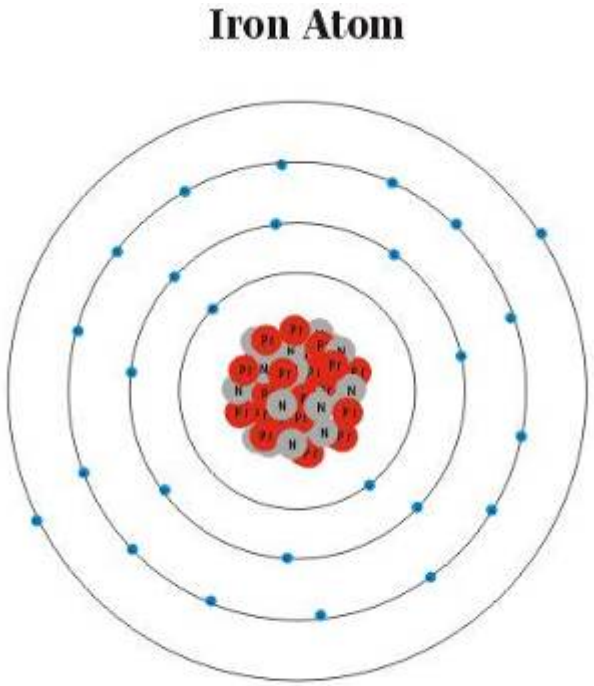
Performance Metals

- 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

Atomic Structure

Atoms consist of:

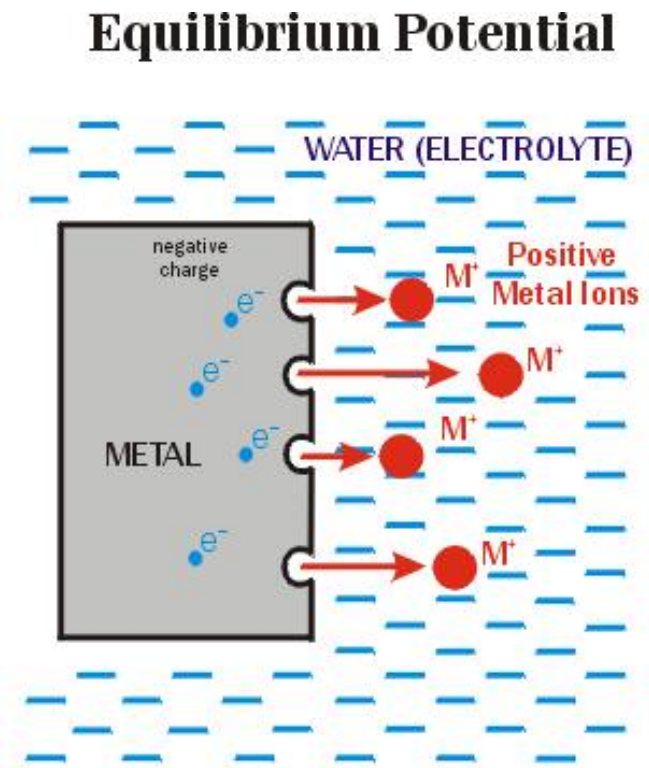
- Nucleus:
  - Protons
  - Neutrons
- Electrons
- Atom is electrically balanced – equal electrons and protons



26 Protons, 26 Neutrons - 26 Electrons

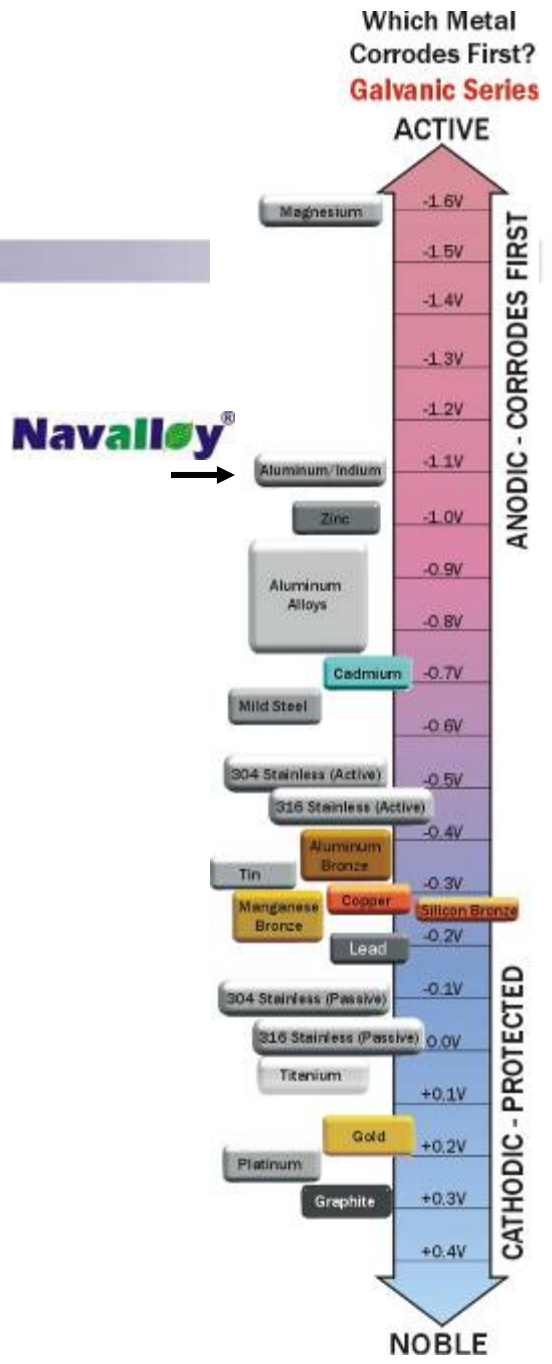
Metals Can Dissolve

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



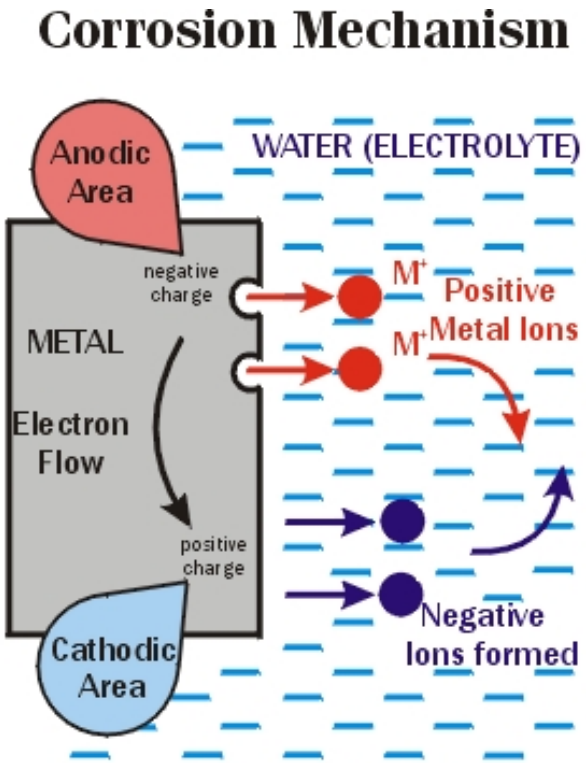
Corrosion

- 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

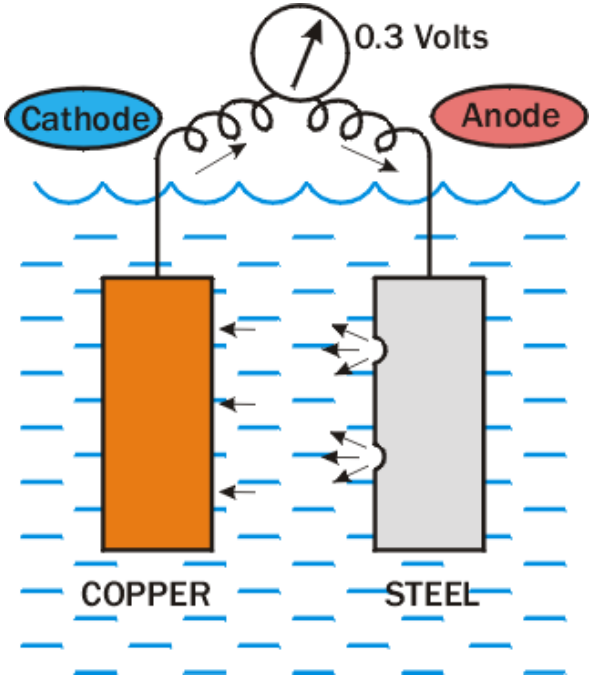


Galvanic Corrosion

- 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:



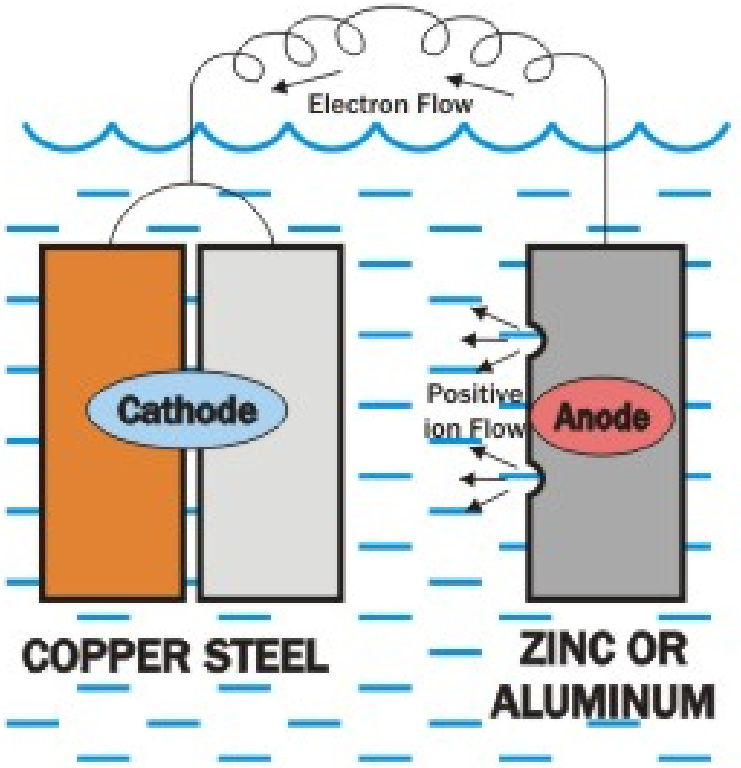
e.g. The steel corrodes to protect the copper!

This is a much faster process

Solution -Sacrificial Anodes

- The solution:
- Add a more "active" material

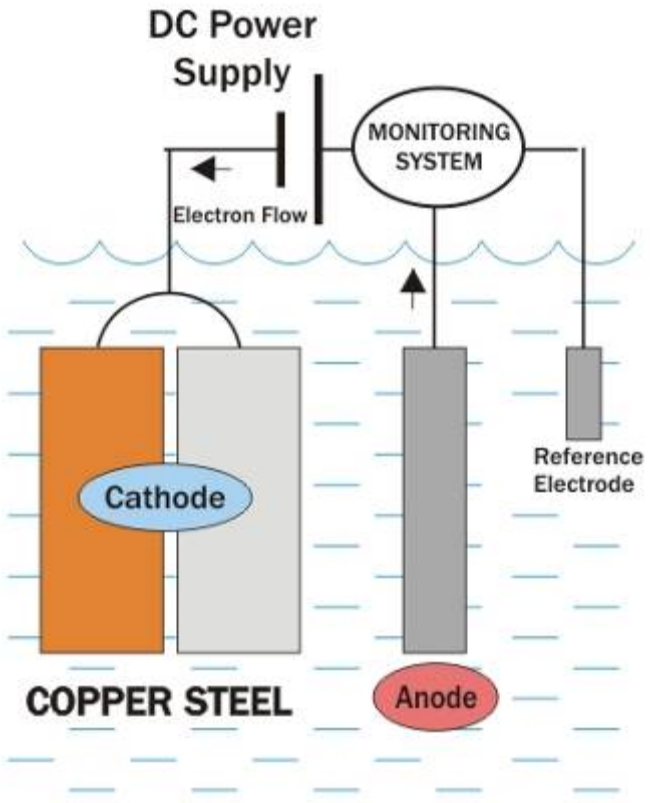
  - Sacrificial Anode
- Protects the steel and copper



(*Invented by Sir Humphrey Davy – 1824*)

Solution #2 – Impressed Current System

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



What is Electrolysis?

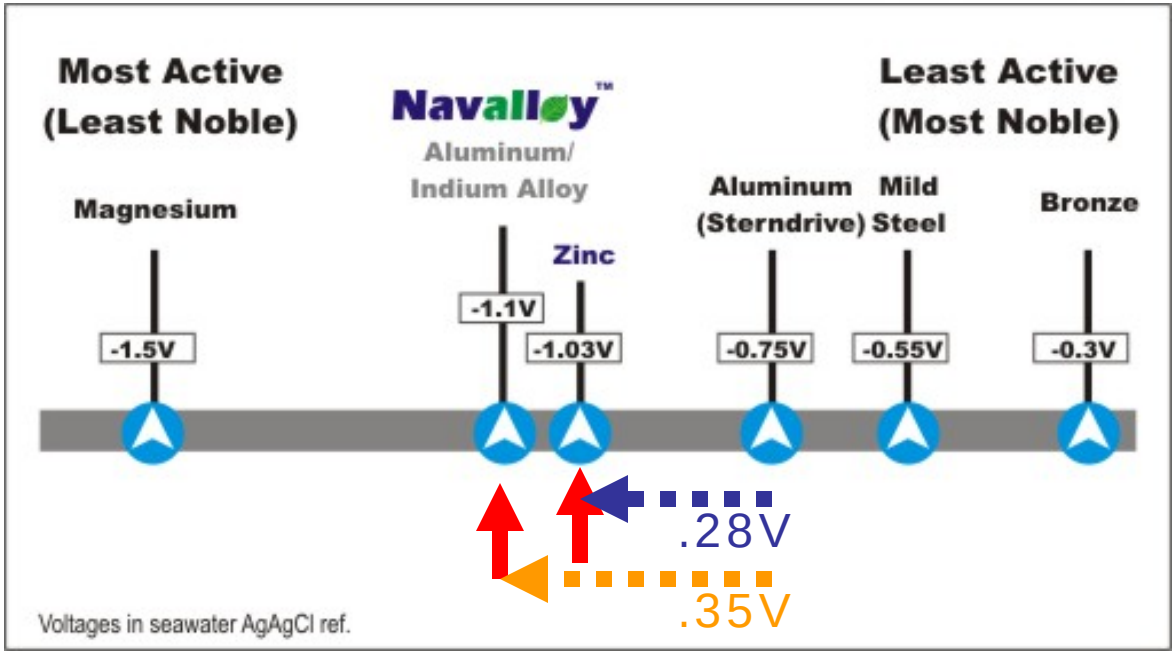
- Process by which water is broken down into Hydrogen and Water by the application of an a direct current
  - At anode: $2H_2O \Rightarrow 4e^- + 4H^+ + O_2$ (gas)
  - At cathode: $4H_2O + 4e^- \Rightarrow 2H_2$ (gas) $+ 4OH^-$
  - In the electrolyte: $4H^+ + 4OH^- \Rightarrow 4H_2O$
  - Add together:

    $2H_2O \Rightarrow 2H_2$ (gas) $+ O_2$ (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

Sacrificial Anode Materials

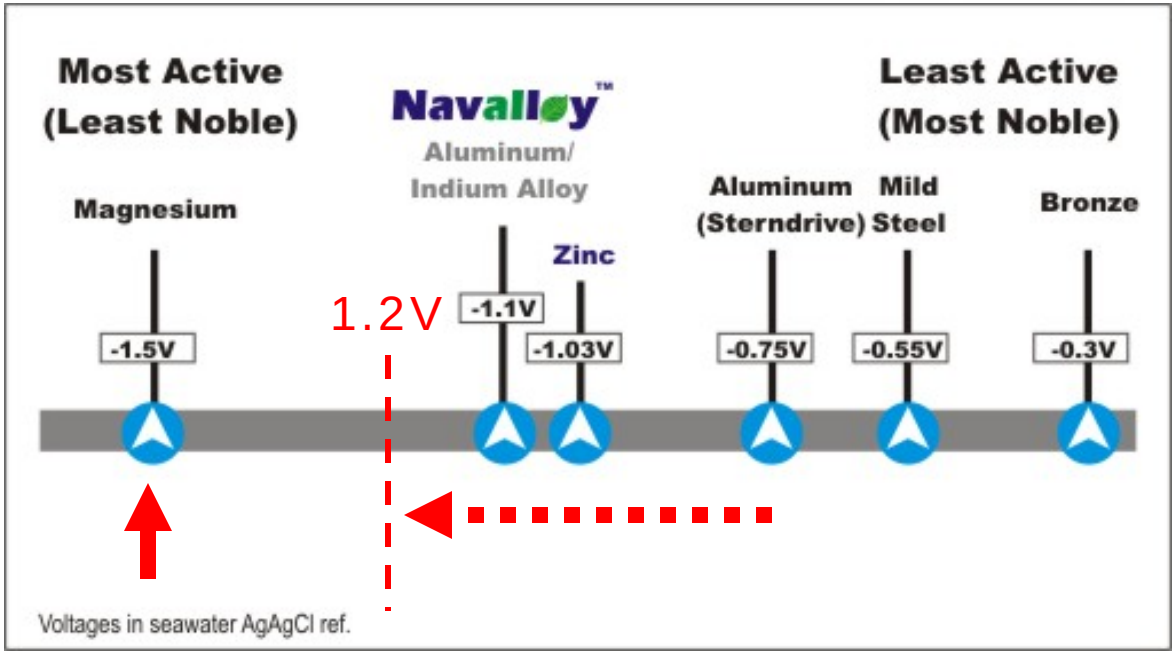


Historically, zinc has been used, because it works as an anode in its natural state.

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

Navalloy™

- 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

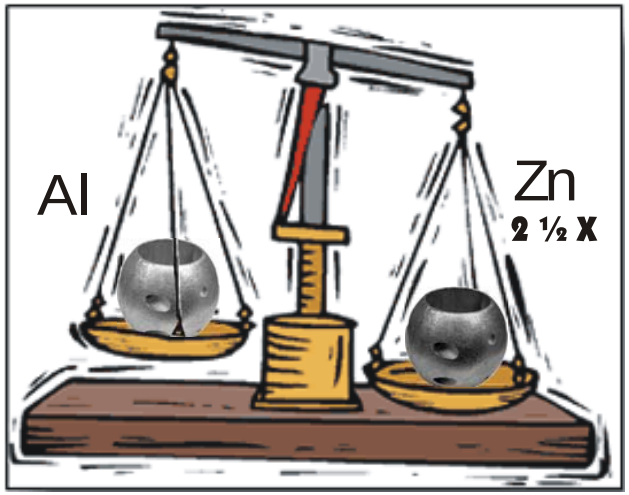
- Suitable for salt and freshwater
  - In freshwater zinc coats over with zinc hydroxide and stops working after approx. two months
  - This can occur in saltwater too – particularly when polluted
  - Aluminum anodes stay active
- Remains active if exposed to air
  - If zinc anodes are removed from water they coat over
  - Aluminum anodes will reactivate when re-immersed

Raytheon Towed Sonar Array

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
  - $O_2 + 2H_2O + 4\ e^- \Rightarrow 4(OH^-)$
- 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

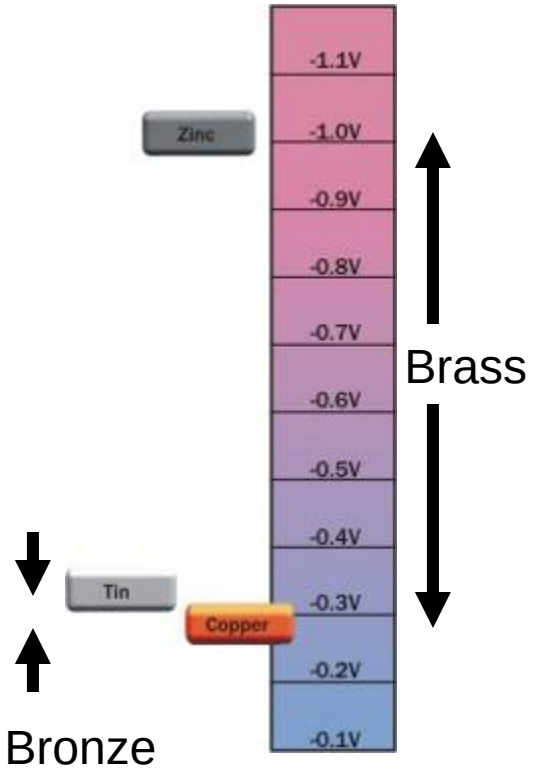
- Corrosion rate doubles for every 10 degree C (18 degree F) rise in temperature

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

- Dealloying
  - Brass (Manganese Bronze) is 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)

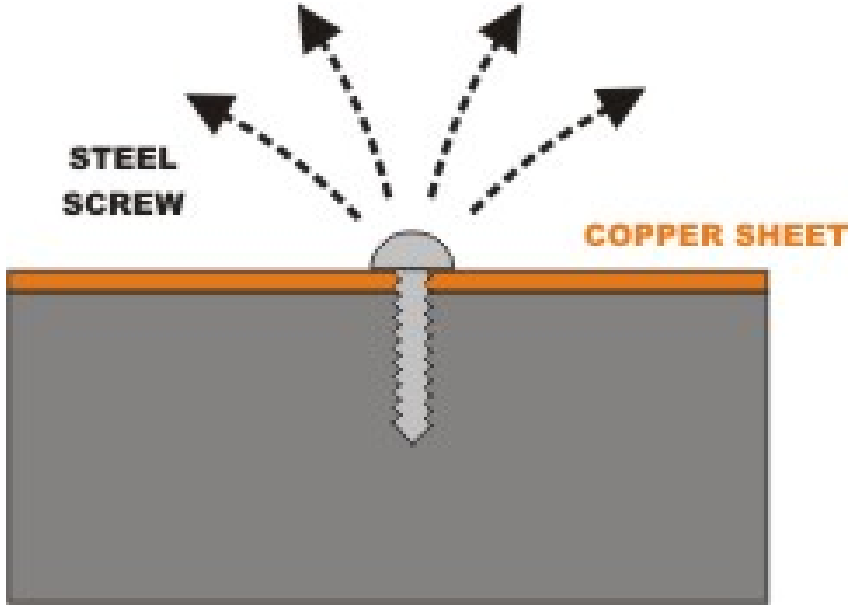
Stray Current Corrosion

Anode/Cathode Ratio of Areas

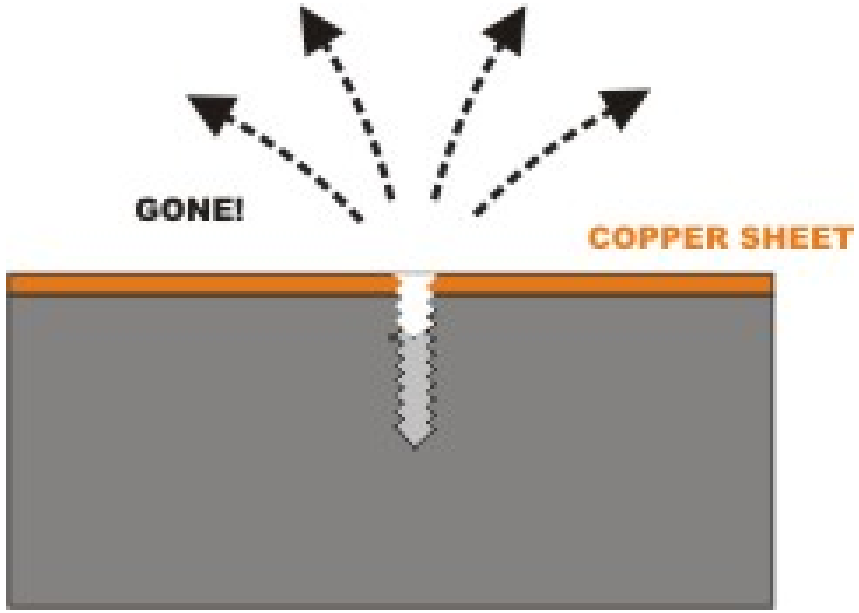
- ***Anodic*** areas need to be as large as possible compared to the ***Cathodic*** areas
  - Current flow is concentrated into surface area of anode
  - E.g. steel screw in copper will disappear quickly whereas in aluminum it will be protected

Anode/Cathode Ratio of Areas

- Consider a steel screw (anodic) holding a copper plate (cathodic)

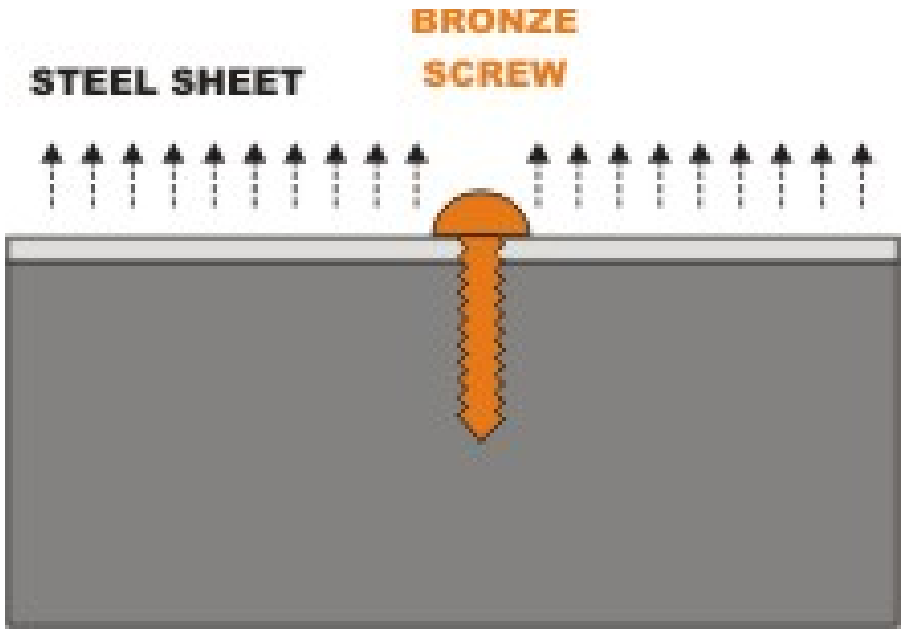


Anode/Cathode Ratio of Areas



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

CORROSION

PERFORMANCE METALS

Sacrificial Anode Wear

CORROSION

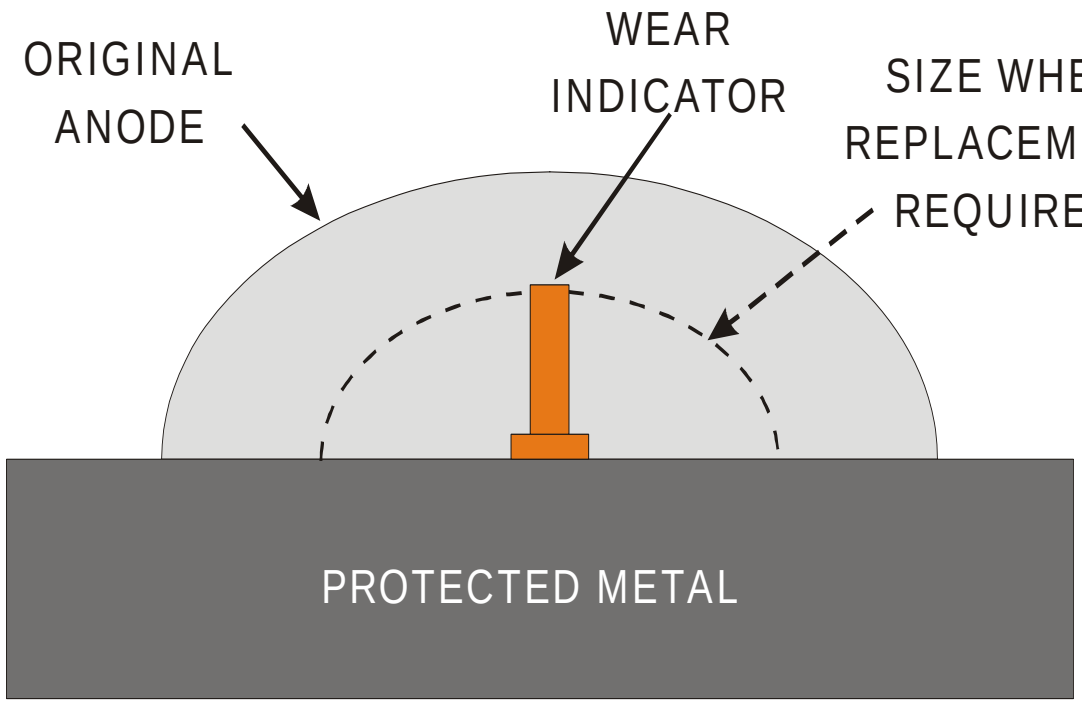
PERFORMANCE METALS

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.

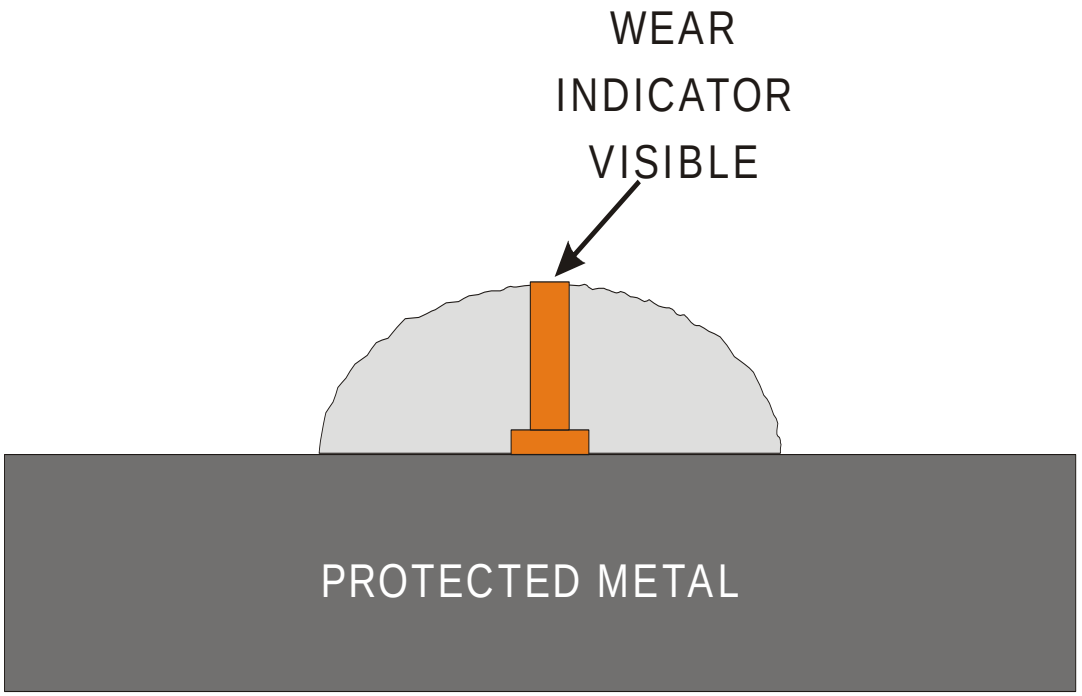
Basic Patent - Original Anode



CORROSION

PERFORMANCE METALS

Basic Patent - Worn Anode



Indicator appears as a “Red Spot” in the surface of the anode.

CORROSION

PERFORMANCE METALS

Recreational Anode Example

CORROSION

Anode Examples

PERFORMANCE METALS

- Range

Anode Examples

- Power Series
  - Finned for extra surface area.

POWER

Anode Examples

- Strap Anodes