

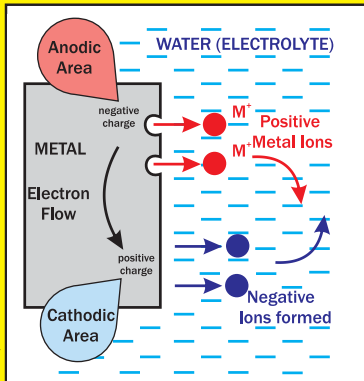
The Boater's Corrosion Reference Card

What is Corrosion?

Corrosion is an electrochemical process of deterioration of metal components when exposed to an aqueous environment (water). This occurs both underwater and in the atmosphere. The deterioration is the process of the metal changing into its oxide form. Steel, for example, will degrade (oxidize) back to its natural stable state - rust (iron ore).

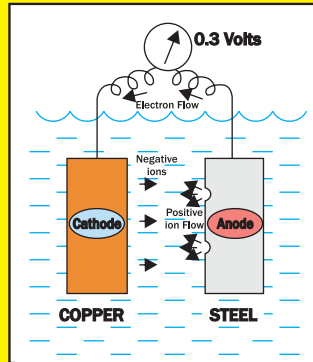
Corrosion Mechanism

The metal atoms at the surface give up electrons and turn into positively charged ions, which dissolve into the water or electrolyte (a liquid that can conduct electricity). Electrons flow through the metal from the corrosion area to other areas, close by, where they form negative ions in the water. The positive ions flow through the water and combine with the negative ions in the opposite direction.



Galvanic Corrosion

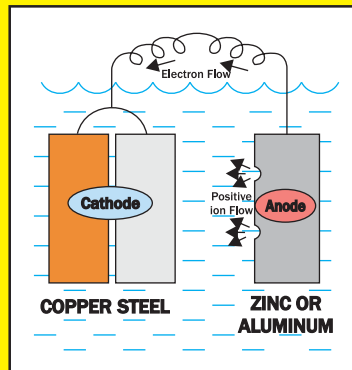
When two different metals (copper and steel in the example) are in contact, electrons will flow from the more negatively charged metal (anode) to the more positive metal (cathode). The voltage generated between copper and steel would be 0.3 volts. The circuit is completed by the loss of positively charged ions from the anode into the electrolyte and the negatively charged ions at the cathode.



This release of small particles (ions) into the water is much more rapid than with one metal alone, and is limited to the corrosion of the steel. The cathode material (copper) is protected.

Sacrificial Anode

If you want to protect both types of metal you must add a third **more active** metal. The most common metal is zinc although magnesium and aluminum are also used. This active metal becomes the anode for both metals.



The zinc or aluminum sacrifices itself to protect the other two metals, hence the term "sacrificial anode."

Why Do Some Metals Corrode More than Others?

All metals tend to be oxidized (corrode), some more easily than others. The relative rate can be plotted on the **GALVANIC SERIES**.

What Factors Affect Corrosion?

Note: some of these factors can vary microscopically at the surface of the metal.

Conductivity of electrolyte - seawater is a good conductor and freshwater a bad conductor, so corrosion is worse in seawater.

Amount of oxygen - Generally, corrosion rates increase in proportion to the amount of oxygen in the water. However, cracks and crevices, which are areas starved of oxygen, become anodic and corrode also.

Presence of pollutants - increases corrosion.

Flow Rate - Will increase corrosion rates. Pitting in stainless steel is reduced however.

Temperature - Higher temperature increases corrosion rates - approximately doubling for every 10°C (18°F).

Stress - Metal under tensile stress (stretched) in combination with corrosion can suffer sudden failure due to stress cracking.

Presence of bio-organisms - There are various types of microorganisms that can contribute to corrosion, either by removing protection or causing a corrosive environment.

Area and Weight of Anodes

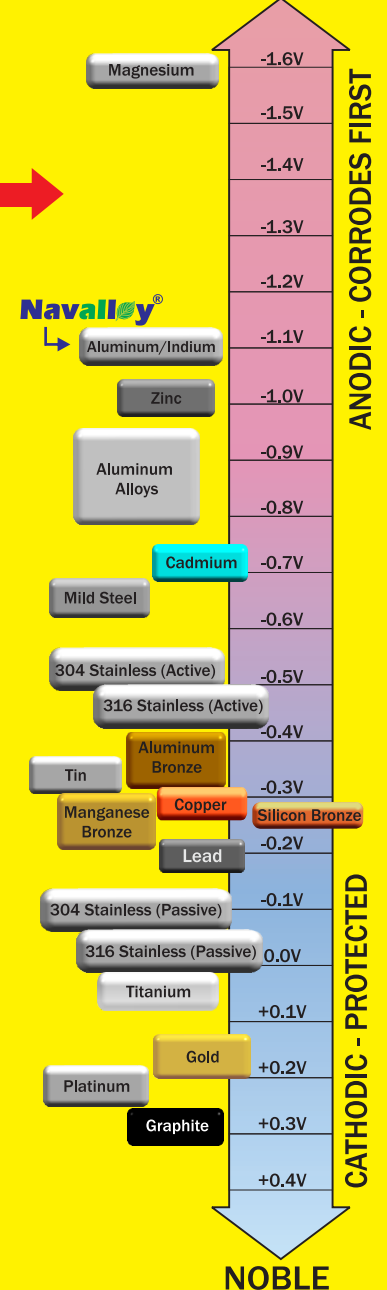
The surface area of the sacrificial anodes determines how much protection (amperage) you get. The weight determines how long they will last. Different anodes have different capacities measured in Amp Hours per Pound.

Cathode to Anode Ratio

The ratio of the area of the cathodic (protected) surface to the anodic (corroding) surface is critical in galvanic corrosion. The smaller the area where the anode is giving up material, the faster it will take place. Ideally the anodic area should be much bigger than the cathodic area. This ratio can be improved by painting the cathodic surface.

Which Metal Corrodes First?
Galvanic Series

ACTIVE



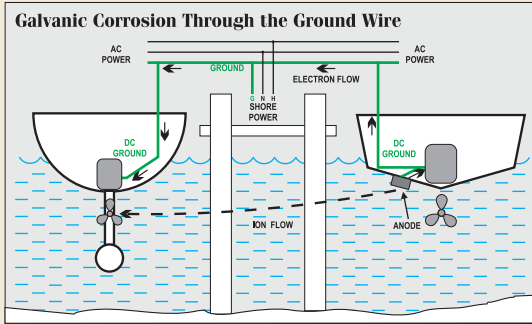
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www.performancemetals.com



Galvanic Corrosion Via The Ground Wire

Connecting into shore power connects your ground to the neighboring boats. If they are not protected by suitable anodes, you will protect them - causing rapid wearing of your anodes. See diagram below.



Galvanic Isolator

A device that is installed in the green ground wire to block galvanic direct currents, but still allow AC to pass.

BEWARE: Make sure your galvanic isolator is rated for the power you use, e.g. 30A or 50A. Poor quality galvanic isolators have been known to start fires, so it's a good idea to get one which is ABYC recognized or UL listed to ensure that it has been properly tested.

Stray Current (Electrolytic) Corrosion

This is corrosion caused by an external current flowing from a battery or other DC source. This current flows out of the metal into the water and causes loss of material or corrosion in the process. Common causes include a bare wire in the bilge or incorrectly wired or installed equipment.

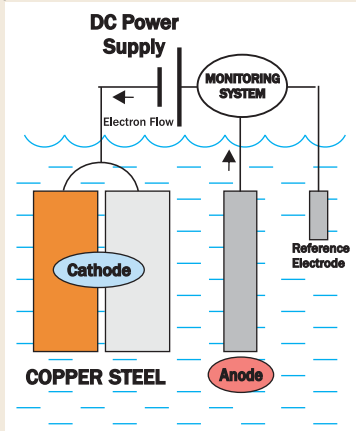
Impressed Current System

Instead of using a sacrificial anode to generate a protective voltage, a DC power source can be used. The principle is the same but the current is monitored and adjusted by the system. A non-corroding material is used for the anode.

The advantage of an impressed current system is that it can develop higher voltages than a sacrificial anode. The disadvantage is that it can "over-protect." Impressed current systems are used on all types of boats and sterndrives.

Bonding

All electrical equipment and underwater metal fittings should be connected to the same ground point (connected to the battery negative terminal). This ensures that all components are at the same voltage, preventing any stray currents occurring.



Sacrificial Anode Materials

	Zinc	Navalloy® (Aluminum)	Magnesium
Voltage (in seawater)	-1.03V	-1.1V	-1.5V
Relative Life (Zinc = 100 Same Size)	100	150	30
Relative Density (Zinc = 100)	100	42	27
Mil.Spec.	MIL-A-18001	MIL-A-24779	MIL-A-21412

Zinc Anodes

Zinc is the most common material used. Zinc anodes are not very effective in freshwater and can stop working after only a few months if not made to mil. specifications. It is a good policy to change them regularly, even if they look OK. Remember, if an anode doesn't wear away it is not working!

Navalloy® (Aluminum) Anodes*

The aluminum alloy used in anodes is very different from normal aluminum. It includes about 5% zinc and a trace of Indium, which prevents the build up of an oxide layer.

Aluminum anode alloy provides more protection and lasts longer than zinc (see chart). It will continue to work in freshwater and is safe for use in salt water. Aluminum is the only anode that is safe for **all** applications

Magnesium Anodes

Magnesium is the most active metal on the Galvanic scale. It can be used in freshwater, but care must be exercised. Magnesium can over-protect aluminum hulls or outdrives in salt or brackish water or even polluted freshwater, causing paint to be lifted with resulting corrosion. Even a few hours immersion can cause severe damage.

Some Facts about Common Marine Materials

Aluminum - An excellent material for marine use (Marine Grades - 5000 or 6000 series). Aluminum is a light, strong metal that is easy to work. It has excellent resistance to corrosion, due to its ability to rapidly form a protective oxide surface film. Unprotected, it may become pitted or covered with a white gritty powder, but these are usually superficial and not harmful. Anodizing eliminates this.

It is, however, very active on the galvanic series (-.76 to -1.00 volts), which makes it prone to galvanic corrosion when in contact with more noble metals. Bronze, Brass or Monel fittings should be avoided or insulated to prevent galvanic action. Stainless steel (316) fasteners are recommended. Aluminum can be over-protected by too much voltage from magnesium anodes in salt, brackish or polluted freshwater.

Brass- An alloy of copper and zinc. Generally not recommended for exposed use. Brass suffers from dezincification, which is the galvanic corrosion of the zinc from the alloy, leaving a spongy brittle component. Note: Manganese Bronze is a **brass** not a true bronze and needs galvanic protection if used underwater.

Bronze- Alloys of copper with little or no zinc. True bronzes are strong and extremely resistant to corrosion both in the atmosphere and immersed. Bronzes may contain tin, aluminum, nickel or phosphorus, but the best and most widely used is silicon bronze. Widely used in fittings and fasteners.

Which Anode Material is Right for Your Boat?

Hull	Inboard				Outdrive
	Wood	Fiberglass	Aluminum	Steel	All
Freshwater (Pure)	Alum	Alum/Mag	Alum	Alum/Mag	Alum/Mag
Freshwater (Polluted)	Alum	Alum	Alum	Alum	Alum
Brackish	Alum/Zinc	Alum/Zinc	Alum/Zinc	Alum/Zinc	Alum
Salt	Alum/Zinc	Alum/Zinc	Alum/Zinc	Alum/Zinc	Alum

DO:

- Change your anodes when they are 50% corroded. A "Wear Indicator" anode will help tell you when to change.
- Make sure they make good electrical contact - remove paint and clean the mounting surface.
- Protect trim tabs individually (do not bond). Although they are usually made from stainless steel they can still corrode and need sacrificial anodes.
- On sterndrives be sure to use new fasteners (usually supplied with anode) - even stainless bolts fail as a result of corrosion.
- Keep a sterndrive immersed in the water so that the anodes can work.

DON'T:

- Do not paint anodes. They will not work!
- Do not use zinc anodes on aluminum outdrives - they will not provide the correct protection.
- Do not mix anode types on sterndrives or outboards - aluminum anodes will try to protect zinc anodes on the same bonding circuit. (However adding aluminum anodes to an "inboard" vessel, protected elsewhere with zinc, will generally improve protection.)
- Do not use magnesium anodes on outdrives in salt or brackish water as they will "overprotect" the aluminum.

Stainless Steel - Widely used strong corrosion resistant material. Stainless owes its corrosion resistance to its Chromium content, which forms an oxide film which is resistant to attack (material is then referred to as **passive**). Nickel improves welding properties. 18/8 (% Chromium and Nickel) is the minimum grade (304 grade). Better is 316 grade which has Molybdenum, which improves corrosion resistance.

If stainless is starved of oxygen (e.g. under seals or barnacles) it loses its protective oxide film and becomes **active**. It will then corrode readily. This can also occur in microscopic crevices resulting in almost invisible corrosion which can cause sudden failure. Good for deck fittings it is not recommended for use underwater (except when galvanically protected as, for example a fastener in an aluminum outdrive).

Wood Hulls - Very prone to deterioration due to various types of wood rot and corrosion caused by metal fittings and fastenings. Silicon bronze fasteners are recommended. Don't use stainless below the water line.

Fiberglass/Composite Hulls - Silicon bronze fasteners are recommended below the water line. WARNING: Carbon (graphite) fibers are electrically conductive and can cause galvanic corrosion between metal components in the structure.

* Navalloy® is a trademark of Performance Metals.