



# MAS NOTE

From the University of Delaware Sea Grant Marine Advisory Service

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## GALVANIC CORROSION

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Galvanic corrosion, often misnamed “electrolysis,” is one common form of corrosion in marine environments. It occurs when two (or more) dissimilar metals are brought into electrical contact under water. When a **galvanic couple** forms, one of the metals in the couple becomes the **anode** and corrodes faster than it would all by itself, while the other becomes the **cathode** and corrodes slower than it would alone. Either (or both) metal in the couple may or may not corrode by itself (themselves) in seawater. When contact with a dissimilar metal is made, however, the self-corrosion rates will change: corrosion of the anode will accelerate; corrosion of the cathode will decelerate or even stop. We can use the seawater **Galvanic Series**, shown in Table 1, to predict which metal will become the anode and how rapidly it will corrode.

The seawater Galvanic Series is a list of metals and alloys ranked in order of their tendency to corrode in marine environments. If any two metals from the list are coupled together, the one closer to the **anodic (or active) end** of the series, the upper end in this case, will be the anode and thus will corrode faster, while the one toward the **cathodic (or noble) end** will corrode slower.

For example, suppose we have an aluminum alloy with a voltage range of -0.7 to -0.9 V (an average of -0.8 V) as shown on the series, coupled to a 300 series stainless steel with an average voltage of -0.07 V. The Galvanic Series predicts that aluminum will be the anode, and the voltage difference between the two alloys will be about 0.73 V (obtained by subtracting the two average voltages). It is this voltage difference that drives the current flow to accelerate corrosion of the anodic metal.

The two major factors affecting the severity of galvanic corrosion are (1) the voltage difference between the two metals on the Galvanic Series, and (2) the size of the exposed area of cathodic metal relative to that of the anodic metal. Corrosion of the anodic metal is both more rapid and more damaging as the voltage difference increases and as the cathode area increases relative to the anode area.

The approximate voltage difference for any two metals can be taken directly from Table 1. It is worth noting that marine slime films composed primarily of microscopic bacteria and diatoms can change the potentials of many of the alloys near the noble end of the Galvanic Series as indicated. The potentials of these alloys become more positive in the presence of slime films, thus increasing the voltage difference when these metals are placed in contact with more anodic alloys. This has been found to increase the corrosion rate of copper, steel, and

**Table 1  
GALVANIC SERIES  
In Flowing Seawater**

<i>Alloy</i>		<i>Voltage Range of Alloy vs. Reference Electrode*</i>
Magnesium	<b>Anodic or Active End</b>	-1.60 to -1.63
Zinc		-0.98 to -1.03
Aluminum Alloys		-0.70 to -0.90
Cadmium		-0.70 to -0.76
Cast Irons		-0.60 to -0.72
Steel		-0.60 to -0.70
Aluminum Bronze		-0.30 to -0.40
Red Brass, Yellow Brass, Naval Brass		-0.30 to -0.40
Copper		-0.28 to -0.36
Lead-Tin Solder (50/50)		-0.26 to -0.35
Admiralty Brass		-0.25 to -0.34
Manganese Bronze		-0.25 to -0.33
Silicon Bronze		-0.24 to -0.27
400 Series Stainless Steels**		-0.20 to -0.35
90-10 Copper-Nickel		-0.21 to -0.28
Lead		-0.19 to -0.25
70-30 Copper-Nickel		-0.13 to -0.22
17-4 PH Stainless Steel †		-0.10 to -0.20
Silver		-0.09 to -0.14
Monel		-0.04 to -0.14
300 Series Stainless Steels ** †		-0.00 to -0.15
Titanium and Titanium Alloys †		+0.06 to -0.05
Inconel 625 †		+0.10 to -0.04
Hastelloy C-276 †		+0.10 to -0.04
Platinum †	<b>Cathodic or Noble End</b>	+0.25 to +0.18
Graphite		+0.30 to +0.20

\* These numbers refer to a Saturated Calomel Electrode.  
\*\* In low-velocity or poorly aerated water, or inside crevices, these alloys may start to corrode and exhibit potentials near -0.5 V.  
† When covered with slime films of marine bacteria, these alloys may exhibit potentials from +0.3 to +0.4 V.

aluminum anodes by a factor of 2 to 5, but to have no effect on the corrosion rate of zinc anodes. It may also change which metal in the couple becomes the anode.

When the two metals in a galvanic couple are close together on the series, such as manganese bronze and silicon bronze,

their voltage ranges overlap, and either one can be the anode, depending on the exact exposure conditions. In this case, more detailed information than is given in this *MAS Note* will be needed to predict the behavior of the couple. Several sources of additional information are listed in the Recommended Reading section.

The effect of the second factor above, the cathode-to-anode area ratio,  $C/A$ , is illustrated in Figure 1 for a rivet in a plate. In both couples A and B, aluminum is the anode, and stainless steel is the cathode. In couple A, the aluminum rivet is comparatively small, and the  $C/A$  ratio is large. In couple B, the situation is reversed: the stainless steel rivet is small, and the  $C/A$  ratio is also small. Corrosion of the aluminum rivet in couple A will be severe. However, corrosion of the large aluminum plate in couple B will be much less, even though the potential difference is the same in each case.

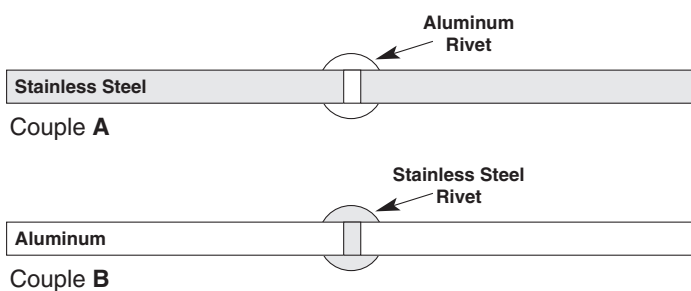


Figure 1. Effect of cathode-to-anode ( $C/A$ ) ratio on galvanic corrosion.

What can you do to minimize galvanic corrosion? First, always try to eliminate the cathodic metal by making all parts of a structure out of the same material. When this is not possible, use nonmetallic, nonabsorbent insulators between the dissimilar metals to prevent current flow. For example, use plastic or ceramic washers and sleeves to isolate bolts as they pass through a plate of a different alloy instead of fiber and paper washers, which absorb water.

Another approach is to make small critical parts out of the more cathodic metal so they will be protected. Always avoid connecting small anodes to large cathodes as in couple A of Figure 1.

Painting a galvanic couple can also be helpful in reducing the corrosion rate, but always be careful to paint *both* the anodic and cathodic members of the couple to keep the exposed  $C/A$  ratio small. If only the corroding member (the aluminum rivet) of couple A were painted, there would still be a large, bare cathode, which would make corrosion of the rivet even worse if the paint coating were scratched.

If the cathodic member of the couple is one of those alloys identified in Table 1 as being influenced by slime films, and if there is a reason not to paint, periodic cleaning of the bare metal surface can minimize the effect of the slime and reduce the corrosion rate of the anode. Periodic cleaning

is not recommended for reducing galvanic corrosion of other alloys in Table 1 because removal of corrosion product films from those metals usually increases corrosion rates.

Finally, let's see how we can use galvanic effects to our advantage in preventing corrosion. Suppose the steel member of a structure is being damaged by contact with silicon bronze. That galvanic corrosion can be stopped by connecting both metals to a third metal more anodic than either of them. According to our Galvanic Series, the third metal in this case could be magnesium, zinc, aluminum, or cadmium. In practice, and for reasons too complex to cover here, zinc works best. (Some of the difficulties and dangers inherent in using the other anode materials are discussed in publications listed below.) The zinc corrodes preferentially to both of the original members of the couple. The steel is now protected, and the zinc is called a **sacrificial anode**. Such anodes are commonly used together with coatings to control corrosion on the underwater portions of boats, ships, and other marine structures. The same principle can be used to protect steel in marine atmospheres if the anodic metal is applied to the steel as a coating. Zinc (called galvanizing) and aluminum coatings are used extensively to protect steel in marine atmospheres. Under fully immersed conditions in seawater, the rule of thumb is that a heavy, hot-dipped zinc coating will protect steel for about one year per mil thickness of zinc applied. One mil is equal to 0.001 inch or 0.025 millimeter. In contrast, electroplated zinc and cadmium coatings are nearly worthless for protecting steel from corroding in seawater.

## RECOMMENDED READING

- Amos, Duncan. 1980. *Marine Corrosion: An Alternative Approach to the Prevention of Corrosion in Wooden and Fiberglass Hull Fishing and Recreational Vessels*. RIU-T-80-004. University of Rhode Island Marine Advisory Service, Marine Bulletin 38. 12 pp.
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