Understanding How Metals Corrode Can Help Build Better Structures

Except for the "precious" metals, such as gold, metals in the refined form are inherently unstable. This instability is what drives the process of corrosion, and it results from the fact that a refined metal is continually trying to revert to its natural state (the mineral). Some metals do this faster than others.

The Galvanic Series ranks corrosion tendencies in specific environments. The Galvanic Series for seawater is a much-used ranking because it's a good, general approximation of how metals behave. See Table 1.

How surface reactions alter a metal's corrosion resistance can be seen in the example of four common construction metals - aluminum, lead, copper and iron. Aluminum ranks as a very active, or corrosion-prone, element in both the AMF Series and the Galvanic Series for seawater, yet it is prized for its low maintenance and slow corrosion rate. This is because aluminum forms a tightly adhering surface film of aluminum oxide when exposed to the air. Under most atmospheric conditions, the oxide protects the aluminum from further corrosion. An exception is found in seashore locations.

When exposed to damp, salty air, most aluminum alloys behave very actively. Sea salt (mostly sodium chloride) destabilizes the normally protective oxide film, leading the localized attack, or "pitting." The reaction is so strong that a thin-gauge aluminum sheet will show perforation after being immersed in warm salty water for only a short period of exposure. However, not all aluminum alloys react so strongly to salt air. Aluminum masts, for example, are very popular on sailboats, but the alloy found in most aluminum flashing, roofing and siding does not stand up to salt, and should not be used near the sea. Aluminum performs much better in industrial atmospheres, although the top choices there are lead and copper.

Lead also forms a surface film of corrosion when exposed to the air. Because this film bonds so tightly with the underlying metal, however, it becomes a barrier to further corrosion. The types of films that form on lead include sulfate, oxides, and carbonates. Lead reacts with sulfur-bearing industrial atmospheres to produce lead sulfate, so it becomes very corrosion-resistant in industrial atmospheres and in areas subject to acid rain.

The green patina seen on older copper structures is a corrosion product consisting of copper sulfates and copper carbonates. The presence of sulfate films means that copper, like lead, holds up well in industrial atmospheres. But there is evidence that atmospheric corrosion of copper, while low, is increasing. Some old-timers remember that the green patina used to take about 25 years to form. It now forms in about 10 years, showing an increased corrosion rate in the underlying metal (although the green patina protects the underlying metal, it does not completely stop the corrosion). Observations of Christ Church in Philadelphia, for example show that its more than 200-year-old copper roof has an annual corrosion rate lower than that seen in contemporary structures.

While lead and copper serve well in heavily industrial atmospheres, zinc and galvanized steel fare poorly under the same conditions. Unlike aluminum, however, zinc and galvanized steel are the metals of choice in seacoast locations, where they suffer little damage from salt-heavy air.

Uncoated iron and steel are quite a different story. Although they are ranked midway in the EMF Series, indicating that they're mildly active metals, they are next to aluminum in the Galvanic Series for seawater. The active behavior of iron and steel results from the type of native oxide that they form. In contrast to the dense, tightly adhering films associated with aluminum, lead and copper, iron and steel oxides tend to be loose, porous, and nonadhering. The oxide flakes off almost as soon as it forms, exposing a fresh metal surface to further oxidation and attendant loss of metal.

An exception to this are products developed called "weathering steel" which modifies the oxide by alloying steel with copper to make the surface film more adherent, thus providing protection. Weathering steel will corrode, but it will usually do so more evenly and at a much slower pace than steel.

It cannot be overemphasized that the corrosion resistance of a metal depends on its naturally forming surface film, as well as on whether or not the film is protective. But corrosion is a complex subject, and several variables can influence a particular metal's performance. Local experience in different regions with each material is usually the best guide to its suitability for a particular use.

Galvanic corrosion - The Galvanic Series assume *freely corroding* metal, unaffected by contact with any other substance. *Galvanic corrosion* is a form of electrochemical corrosion that occurs when two dissimilar metals come together in the presence of an electrolyte to form an electrical couple, known as a galvanic couple. In building systems, the electrolyte is usually ordinary moisture, whether rainwater of high atmospheric humidity.

When two metals form an electrical couple, an exchange of electrons takes place, its direction and intensity governed by each metal's ranking in the Galvanic Series. The farther apart the two metals are on the Galvanic Series, the greater the potential for corrosion (see Table 2). This exchange protects the more noble (less active) metal, while causing the more active metal to corrode even faster. The more active metal gives up electrons, sacrificing itself to protect the more noble. We call the active, corroding metal the "anode" and the noble, non-corroding metal the "cathode". After the anode corrodes completely away, the cathode will again begin to corrode as reflected by its position in the Galvanic Series.

Although builders rightly see galvanic couples as something to be avoided, the process has its uses. Boaters, for example, use sacrificial anodes - buttons or bars of an aluminum magnesium alloy that corrode instead of more desirable metallic boat parts - to protect engine parts or propellers. And galvanic couples are the mechanism by which galvanizing works.

Galvanizing means simply overlaying steel with zinc, either by plating or by dipping the steel in molten zinc. An undamaged piece of galvanized steel will corrode at the same rate as a similar piece of zinc. Once the zinc coating is perforated (by mechanical damage, for example), the zinc forms a galvanic couple with the steel, the zinc corroding to protect the steel. The zinc will continue to protect the steel until most of the zinc is gone.

When the zinc is gone, you may begin to see a lot of thin patches of rust. What this means depends on whether the zinc was applied by plating or dipping. On an electroplated surface, such as a galvanized-metal roof, the rust indicates that corrosion of the underlying metal has begun. On a hot-dipped galvanized surface, however, the zinc actually diffuses partway into the steel. The initial patches of rust mean that the pure zinc overlay has corroded away. Thus a piece of hot-dipped galvanized steel will give you some warning before the steel begins to corrode.

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NOTE: See CLI technical capabilities in corrosion evaluation, consulting and failure analysis.

TABLE 1

The Galvanic Series for Seawater

Most cathodic, or passive	Graphite Gold Silver
Most anodic, or active	Passive stainless steel Nickel Siler Solder Copper Brasses Tin Lead Lead-tin solder Active stainless steel (most stainless steel fittings) Cast Iron Wrought Iron Copper Steel Carbon Steel Aluminum Magnesium and magnesium alloys Zinc and galvanized iron and steel

TABLE 2

Galvanic corrosion potential between common construction metals									
	Alum.	**Brass**	**Bronze**	**Copper**	**Galvan Steel**	**Iron/ steel**	**Lead**	**Stain steel**	**Zinc**
Aluminum		1	1	1	3	2	2	3	3
Copper	1	2	2		2	1	2	1	1
Galvanized steel	3	2	2	2		2	3		3
Lead	2	2	2	2	3	3		2	3
Stainless steel*	3	1	1	1	2	2	2		1
Zinc	3	1	1	1	3	1	3	1	

1. Galvanic action will occur with direct contact.
2. Galvanic action may occur.
3. Galvanic action is insignificant between these metals. * Active stainless steel