

Galvanic Corrosion

— Knowing how it works and steps to protect against it are important

by:

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Anyone that has ever worked on rehabbing an older home has probably encountered a plumbing connection where an old galvanized steel pipe that has been connected with a newer copper fitting such as shown in **Figure 1** is in bad shape. The discovery of this condition may be purely accidental, or more likely, if such a connection has been in-place for any length of time, the ticking time bomb represented by this condition has finally gone off and it is leaking or broken.

So what is this condition? It is a classic case of galvanic corrosion. Fastener engineers, designers and end users, especially in instances where metals are being clamped in wet environments, must be very wary of this possibility and make efforts to avoid future problems.

Although galvanic corrosion is a pretty well understood corrosion mechanism, the terms can get pretty confusing for those that do not work with it every day. This article is intended to clarify and simplify the concepts.



Fig. 1 — Copper fitting connected to steel pipe.

What is Galvanic Corrosion?

First of all, one must understand that galvanic corrosion is just one of several mechanisms by which metals can corrode. Everyone understands that corrosion is about parts breaking down and/or physically changing in less than positive ways. For example, steel parts rust, which makes them weaker and corroded in appearance. Galvanic corrosion is an electro-chemical process, meaning that a chemical reaction is accompanied by an electrical current. For galvanic corrosion to occur, three conditions must be met. They are:

- The paired metals must be dissimilar, i.e., possess differ-

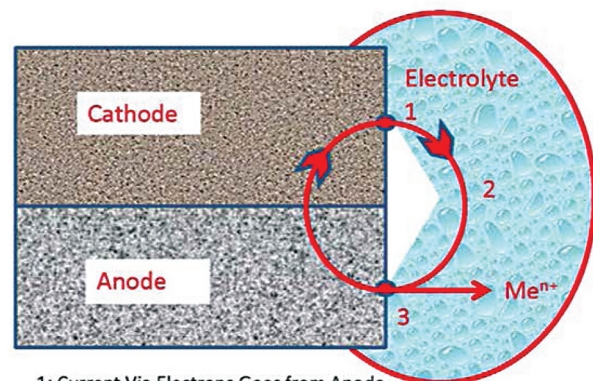
ent chemical potentials (chemical potential refers to the tendency of a metal to give up electrons to an aqueous solution in which it is in contact. For example, if we listed the chemical potentials of metals in descending order we find that magnesium is greater than aluminum, which is greater than iron, which is greater than copper, which is greater than silver or gold). A difference in chemical potential manifests itself as an electrical potential difference, and hence a tendency for an electrical current to flow.

- There must be metal-to-metal contact (just like the prongs of a plug will not transfer electric current unless they are in contact with the mating parts of an electrical receptacle, to complete the electric circuit needed for galvanic corrosion the metals must be in electrical contact with one another).
- There must be an electrolyte that contacts all the involved metal surfaces. An electrolyte is simply a solution containing ions, which are charged electrical particles. This solution, usually a liquid, completes the necessary electrical circuit, which allows an electrical current to flow so that chemical reactions can occur at the surfaces of the metals.

Removing any of these three factors eliminates the possibility of galvanic corrosion. As is clear from these conditions, an electrical circuit is essential for galvanic corrosion to occur. Therefore, if the circuit can be broken, galvanic corrosion cannot occur.

How it Works

When the three conditions described above are met, a galvanic couple, i.e., an electric circuit, is created. In an electrical circuit, electrons or ions flow between regions that are at different electrical potentials. In a galvanic couple, there are two such regions, the cathode and the anode. **Figure 2** illustrates how the current flows between the contacting metals, creating a cathodic reaction at the cathode and electrolyte interface, returning through the



- 1: Current Via Electrons Goes from Anode to Cathode, Cathodic Reaction, Reduction of Electrolyte
- 2: Current Via Ions Passes from Cathode Through Electrolyte Back to Anode
- 3: Anodic Reaction, Oxidation of Metal (Me^{n+})

Fig. 2 — Diagram of galvanic corrosion mechanism.

electrolyte to the anode, where an anodic reaction occurs resulting in the oxidation (corrosion) of the anode metal. Therefore, when dissimilar metals contact and a galvanic couple occurs, the metal acting as the anode corrodes while the metal acting as the cathode remains intact.

Galvanic Series

Understanding the impact of pairing dissimilar metals is very important when considering the potential for galvanic corrosion. Fortunately for the designer, many resources exist to illustrate the relative differences of different metals to one another. **Figure 3** shows a table of the galvanic series of many common metals related to fastened joints. In this table, taken from the **Industrial Fasteners Institute’s** “Fastener Technology Handbook”, materials that are reasonably compatible with one another have been grouped together. Pairing fasteners with clamped materials that are in different groupings can be potential corrosion problems. Additionally, some metals can show up in different places on the scale of **Figure 3**. In particular, those materials that contain significant contents of nickel and chromium can be either more anodic (referred to in the table as “active”) or more cathodic (referred to in the table as “passive”). These materials, which include stainless steels, are made passive by passivation, which means they undergo a process which develops favorable surface oxides that lower the metal’s electrical conductivity and improve corrosion resistance.

Other Factors Affecting Galvanic Corrosion

Electrolytes: One of the determining factors for galvanic corrosion is the presence of an electrolyte (a solute with ions). These electrolytes might be present due to contact from direct immersion (such as a part on a boat below the waterline), rain, condensation, spray or contact with a continuously wet surface such as soil, a gasket that has capillary properties or some kind of porous foreign deposit. Electrolytes also possess degrees of their ability to conduct currents so that there are weak and strong electrolytes. Electrolytes that possess chlorides such as salt water are particularly strong and aggressive. This means for example, that salt water is a better conductor of electricity because of its ion content than drinking water.

Generally, the better an electrolyte’s conductivity (a “strong” electrolyte), the faster the expected rate of corrosion and the larger area of damage. Normally, corrosion first appears on the anodic metal part at the point of contact with the cathodic metal. If the electrolyte is weak, the corrosion will be slow and remain localized to this area of contact. However, if the electrolyte is strong, the corrosion may be quite rapid and the corrosion area spread relatively far from the contact point.

Relative Size of Anode and Cathode: The size of the anode and cathode can have a dramatic influence on the rate and effect of galvanic corrosion. If the anode is small relative to the cathode, the rate and severity of corrosion of the anode will be significant. On the other hand, when

(+) Corroded End (Anodic)
Magnesium
Magnesium Alloys
Zinc
Aluminum (1100 Series)
Cadmium
Aluminum (2024-T4)
Steel and Iron
Cast Iron
Chromium-iron (active)
Ni-Resist cast iron
Type 304 Stainless (active)
Type 316 Stainless (active)
Lead tin solders
Lead
Tin
Nickel (active)
Inconel® nickel-chromium alloy (active)
Hastelloy® Alloy C (active)
Brasses
Copper
Bronzes
Copper-nickel alloys
Monel® nickel-copper alloy
Silver solder
Nickel (passive)
Inconel® nickel-chromium alloy (passive)
Chromium-iron (passive)
Type 304 Stainless (passive)
Type 316 Stainless (passive)
Hastelloy® Alloy C (passive)
Silver
Titanium
Graphite
Gold
Platinum
(-) Protected End (Cathodic)

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Fig. 3 — Galvanic series table.

the cathode is small relative to the anode, the anode will still exhibit corrosion, but at a much slower rate.

One real-life example is the joining of stainless steel plates with unplated carbon steel fasteners. A quick review of the galvanic series chart shows that the carbon steel fasteners will act as the anode and the stainless steel plates as the cathode. Because the fasteners will have a much smaller surface area than the stainless plates, they will be subject to relatively quick corrosion. If this scenario is reversed, so that the fasteners are stainless steel and the plates are carbon steel, the plates will still experience corrosion, but at a much slower rate and with less severity.¹ **Continued...**

Using the Galvanic Mechanism to Advantage

Ironically, what seems to be a negative corrosion mechanism, can actually be turned to practical advantage. There are many applications where protecting a structure in a system is critical. This is particularly common with tanks, underground pipes and ship structures. A very common everyday example is the anode rod found in many residential hot water heaters. This rod is made of magnesium or aluminum and is designed to sacrifice itself and protect the steel tank. Many similar sacrificial systems can be found protecting underground tanks, metal ship hulls and buried pipes.

In a similar vein, many metallic types of plating utilize this same science. Take for example, the standard zinc plating. The zinc layer is the anode and the base steel below is the cathode. When exposed to service conditions the zinc plating will sacrifice itself and continue to corrode preferentially even after some of the underlying steel is exposed. In this way the steel is protected for some time before it too will begin to corrode.

Guidelines for Galvanic Corrosion Prevention

- Do not pair dissimilar metals or take care to only pair metals that fall within the same galvanic series grouping.
- Create a barrier between contacting components to eliminate an electric circuit. This is most often accomplished with plastic washers, bushings, gaskets or paint. It is important to consider that contact may be in more places than just underneath the head of a bolt or the face of a nut.
- Prevent the entrapment of electrolytes and also make provisions for drainage.
- Design the fasteners to be cathodic and the clamped material to be anodic. Additionally, keep the fastener surface area as small as possible relative to the anodic surface area. One might consider using fewer, smaller, high-strength fasteners. Again, the primary goal here is to have as large an anode to cathode surface area ratio as possible.
- If inhibitors or barrier coatings are utilized, it is best to cover both the anode and cathode. However, if only one material can be covered, it should be the cathode.
- If necessary, design a nonfunctional sacrificial anode protection system.
- If several different metals comprise a system, choose the most noble (that is the most cathodic on the galvanic series chart) for the more important or least accessible components.²
- Graphite is a nonmetallic material that is highly noble in character. Care must be taken to avoid using lubricants or plastic, rubber or other gasket materials that use graphite fillers, as these materials could unwittingly create a galvanic couple.

Conclusion

Like any type of corrosion, galvanic corrosion can be insidious and quite disastrous. However, understanding how it works and the steps that can be taken to protect against it can go a long way in preventing problems in the field. In fact, unlike most corrosion or potential failure mechanisms, understanding the galvanic corrosion mechanism can be an important tool for the designer to protect critical system components against corrosion and failure.

To learn more about galvanic corrosion prevention, contact the author at **NNI Training and Consulting Inc.**, or visit the company's website listed below.

www.NNITraining.com

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References:

- ¹ *Industrial Fastener Institute, "Fastener Technology Handbook", First Ed., (Independence OH: Industrial Fasteners Institute, 2010), 132-135.*
- ² *Alfred E. Bauer, "Stainless Steel in Waters: Galvanic Corrosion and its Prevention", (Nickel Development Institute), 6-7.*

Company Profile:

NNI Training and Consulting Inc. is a dynamic, entrepreneurial 'knowledge provider' that offers training and consulting services to small and mid-sized companies. Our specific expertise is in cold heading, fasteners, fastener and application engineering, and automotive, industrial, and aerospace parts supply. NNI Training and Consulting provides training based on a strong foundation of theoretical knowledge combined with practical understanding and applied skills. NNI Training and Consulting offers consulting services on fasteners, fastener engineering and fastener quality; quality management systems and certifications; and business and sales development and strategy. Offering customers an unbiased perspective, technical expertise, solid business acumen, new ways of doing things and keen insight is the company's specialty.

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