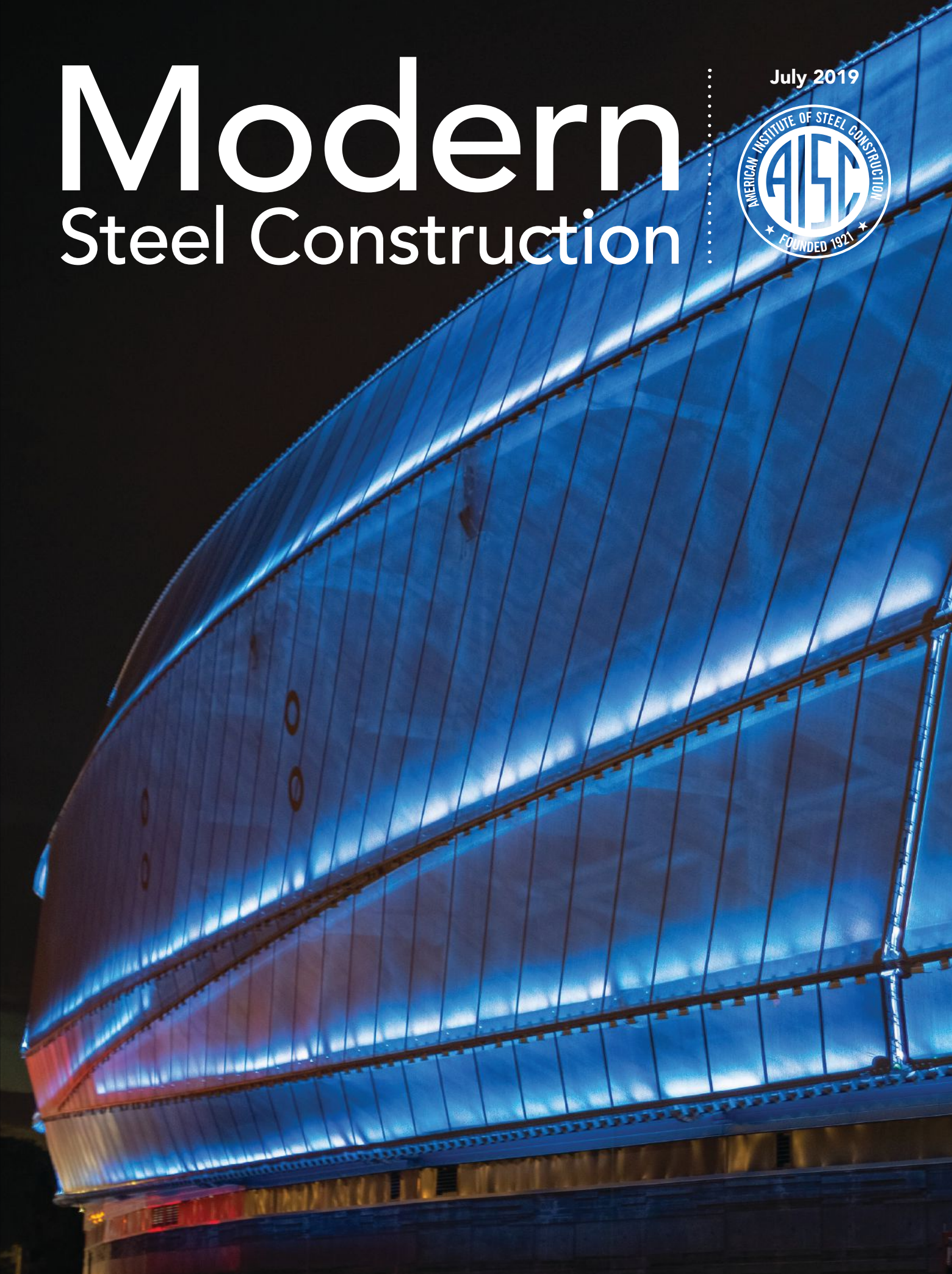


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steelwise OPPOSITES ATTRACT

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A primer on galvanic corrosion of dissimilar metals.

ENGINEERS AND ARCHITECTS often encounter conditions where dissimilar metals are in contact.

When these situations arise, it is appropriate to consider the corrosion susceptibility of the materials. Although the term corrosion can be broadly applied to any degradation of a metal and can have a variety of causes, this article will discuss the main drivers of galvanic corrosion, which occurs between two dissimilar metals, and offer some strategies to help engineers assess and mitigate its effect in structural applications.

What is Galvanic Corrosion?

Galvanic corrosion typically occurs when dissimilar metals are in electrical contact with each other in wet or humid conditions. It is caused by an electrochemical reaction between the two metals where the transfer of electrons from one metal to the other causes one metal to be oxidized (corroded) at the expense of the other. The reaction occurs when the materials have been connected in a galvanic cell, which is made up of four essential elements (see Figure 1 for an illustration of the relationship between these elements):

1. An **electrolyte** is a conductive liquid or gel that allows the transfer of electrons between the two metals—e.g., water.
2. An **anode** is the negative terminal of a galvanic cell, from which electrons are transferred, resulting in oxidation and section loss of the metal. The anodic metal has the greater negative electrical potential of the two metals in contact.
3. A **cathode** is the positive terminal of a galvanic cell, to which electrons are transferred. No degradation occurs at the cathode. The cathodic metal has the lesser negative electrical potential compared to the anode.
4. An **electrical connection between the anode and cathode** that allows the electrochemical reaction to occur. In immersed conditions, the electrolyte may produce the electrical connection.

If an electrolyte is not present or if the metal ions don't have a mechanism that will allow them to transfer between the materials (i.e., the metals are not in contact) then galvanic corrosion cannot occur. Surface wetting, which can act as an electrolyte, typically occurs when the relative humidity of the environment is greater than 80%. In a marine environment where chloride contamination of a surface has occurred, surface wetting can occur with a relative humidity as low as 30%, which in practice results in the permanent presence of an electrolyte on the surface of a structure. In addition, the rate of galvanic corrosion increases with the conductivity of the electrolyte, so rapid galvanic corrosion can occur in marine environments.

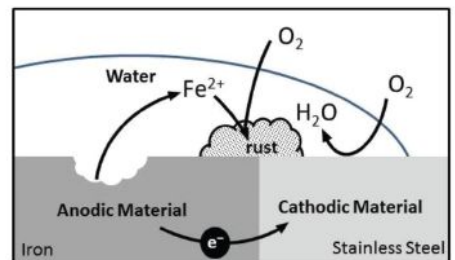
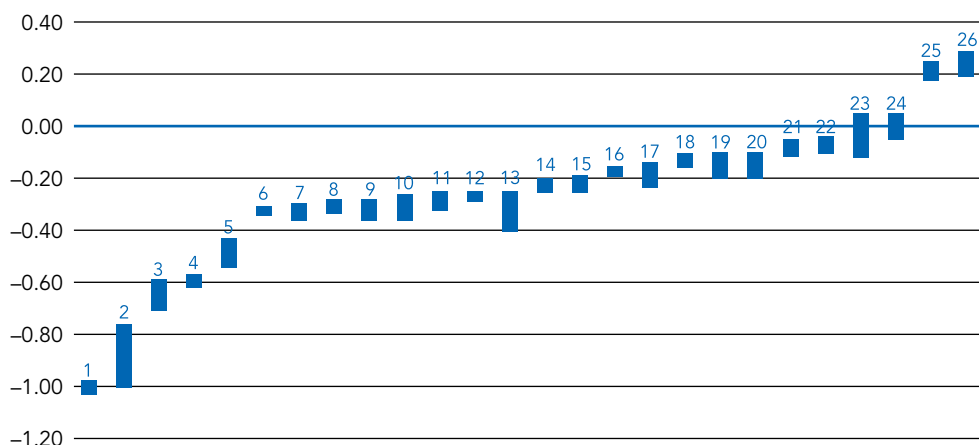


Fig. 1. An example of a galvanic cell.



1. Zinc
2. Aluminum alloys
3. Low-carbon steel, cast iron
4. Low-alloy steel
5. Austenitic nickel cast iron
6. Tin
7. Copper
8. Manganize bronze
9. 505n-50Pb solder
10. Stainless steel (AISI types 410, 416) – passive
11. Tin bronze
12. Silicon bronze
13. Brass
14. Stainless steel (AISI types 430) – passive
15. Lead
16. Inconel 600 – passive
17. Nickel-aluminum bronze
18. Silver
19. Nickel
20. Silver brazing alloys
21. Stainless steel (AISI types 302, 304, 321, 347) – passive
22. Stainless steel (types 316, 317) – passive
23. Titanium
24. Alloy 20 stainless steels – passive
25. Platinum
26. Graphite

Fig. 2. Galvanic series of common metals: potential energy (in volts) when in saltwater.

In many cases, the effects of galvanic corrosion are negligible. The severity of galvanic corrosion depends on the difference in the electrical potential between the contacting metals. A chart showing the relative potentials of different metals, known as the galvanic series, is shown in Figure 2. The galvanic series is given in the figure based on saltwater conditions. However, the actual electrical potential of a metal will vary based on the electrolyte. For more exotic metal alloys, the electrical potential can be measured in a test laboratory according to ASTM G82: *Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance*. Note that stainless steels have different potentials according to whether they are passive or active (corroding) due to a breakdown of their passivating layer. The galvanic series shown in Figure 2 provides the electrical potential for stainless steels in their passive (normal) state rather than their active state, as this condition of stainless steel has an electrical potential that is further away from that of carbon steel.

In general, galvanic corrosion will not occur if the difference in potential is less than 200mV, but in an aggressive environment dissimilar metal corrosion can occur with a potential difference as small as a few tens of millivolts.

Galvanic corrosion is also affected by the relative surface areas of the metals in contact. If the surface area of the anode is much smaller than the surface area of the cathode, then the flow of electrons will have a high current density in the anode, resulting in rapid corrosion of the anodic metal. If the surface area of the anode is much greater than the area of the cathode, then the current density at the anode will be low and the corrosion will typically be negligible. As a rule of thumb, a cathode-to-anode surface ratio of at least 10:1 is optimal for minimizing galvanic corrosion.

The severity of galvanic corrosion can be predicted for construction materials of different potentials and surface areas using design charts—and of course, fasteners have a smaller surface area than structural members. See Figure 3 for a chart listing the corrosion susceptibility of different fastener/member metal couples.

Fig. 3. Galvanic corrosion potential between steel and common construction metals.

Galvanic Corrosion of Dissimilar Metals		Fastener					
		Stainless Steel	Copper	Brass	Carbon Steel/ Iron	Aluminum Alloys	Galvanized Steel (Zinc)
Approximate Electrical Potential, Measured in Volts*		-0.05 to -0.25	-0.36	-0.25 to -0.4	-0.61	-0.80	-1.00
Member	Carbon Steel/Iron	Member may corrode	Member may corrode	Member may corrode	—	Fastener may corrode	No significant corrosion**
	Galvanized Steel	Member may corrode**	Member may corrode**	Member may corrode**	No significant corrosion**	No significant corrosion	—
	Stainless Steel	—	No significant corrosion	No significant corrosion	Fastener likely to corrode	Fastener likely to corrode	Fastener likely to corrode

* Volts in saltwater. Note that compatibility of materials should be assessed based on a galvanic series that is applicable to the exposure environment. For example, the difference in electrical potential between aluminum and stainless steel is typically negligible in general atmospheric conditions but is more pronounced in saltwater environments.

** Zinc coating is likely to corrode but is sacrificial.

Preventing Galvanic Corrosion

The simplest mitigation strategy is to remove any one of the four components from the galvanic cell. This may involve one or more of the following:

Elimination of the electrolyte (such as water) from connecting materials. Materials wholly enclosed inside of buildings with controlled environments are typically not susceptible to galvanic corrosion. Exceptions can occur on surfaces where condensation can form, or where the internal humidity is high. Coatings can also be used to keep an electrolyte from a surface, but the coating must be durable and free of defects to provide reliable protection.

Electrical isolation of the anodic and cathodic metals using an electrically insulative material. If there is no electrical connection between materials, the galvanic cell cannot form and galvanic corrosion cannot occur. Effective electrical insulators are materials that have high dielectric strength and low capacity for water absorption. Various isolation kits are available in the market, which often include materials manufactured from neoprene, mylar, nylon, PTFE (Teflon), or similar insulators. For bolted connections, an isolation kit may include plastic washers, bolt sleeves, and shims to isolate the dissimilar metals. When selecting alternative washers and shims that are to be used in a bolted joint, the washer

and shim strength and stiffness must be evaluated for compatibility with the loading condition—e.g., if the bolt is loaded in tension, the washer must provide adequate strength and stiffness to transfer and distribute the load to the connected parts.

The designer should also note that *RCSC Specification* Section 3.1 does not allow compressible materials to be included within the grip of a high-strength bolt assembly and states that “any materials that are used under the head or nut shall be steel.” Since an insulator is necessary under the head and nut to maintain electrical isolation, the engineer cannot rely on the installation procedures from the *RCSC Specification* for these bolts and must evaluate the effect of the compressible material on the joint—while recognizing that the joint may not develop pretension and will need to be kept from loosening in service.

Using materials of similar electrical potential. If possible, the difference in electrical potential between contacting metals should be limited, and/or the design should ensure that the anodic metal has a much greater surface area than the cathodic metal. The environment should also be considered, as any surface contamination with chlorides (such as in a marine environment or surfaces exposed to deicing salts) can result in very aggressive galvanic corrosion.

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When Corrosion is a Good Thing

Is corrosion always a bad thing? No! Although not strictly a galvanic form of corrosion, two common corrosion protection methods use the concept of corrosion to your advantage:

Hot-dip galvanizing. In some cases, sacrificial anodes are coupled to structural materials to protect them from corrosion. The most common example of this is a zinc coating used to galvanize carbon steel, where the zinc is not relied upon to perform a structural function and the zinc material is slowly consumed to protect the underlying steel. Although not technically considered to be galvanic corrosion, the science behind this process is similar in that an anode (zinc) is designed to corrode over time and force the structural load carrying element (carbon steel) to be the cathode.

Cathodic protection. Cathodic protection systems come in two types: sacrificial anodes and impressed current systems. Both apply the concept of a galvanic cell with the protected material acting as the cathode (positive pole of the cell). These systems are typically most effective in buried or immersed conditions where the soil or water is available to act as an electrolyte. Sacrificial anodes without an external power source are often used for small structures such as buried tanks, piles, etc. These systems are low-maintenance and easy to install. For larger structures such as pipelines and wharves, an impressed current system may be more cost-effective—though the designer should consider that these systems have the potential to be turned off during a structure’s life, resulting in a loss of protection. In above-grade conditions, cathodic protection systems are not typically effective for steel frames as there is not an electrolyte readily present.

The table at right provides a few typical conditions of dissimilar metals in contact that a structural engineer may be asked to consider.

We hope this discussion has given you a better understanding of galvanic corrosion as it relates to structural design. For more nuanced conditions such as enclosure design, conditions involving water flow, or materials subjected to unusual exposures, please consider additional reading or consulting a building scientist or metallurgist for assistance. ■

Condition	Level of Concern
A carbon steel bolt is used in a stainless steel beam within a sealed plenum space of an office building.	Because there is no electrolyte (water or humidity) present in the space, a galvanic cell will not be expected to form, and galvanic action is typically not a concern.
A stainless steel walking surface is supported on a carbon steel pedestrian bridge with stainless steel bolts.	In an outdoor environment, a galvanic cell may form between these materials. The stainless steel deck should be isolated from the carbon steel structure. The stainless steel bolts will also tend to cause corrosion of the steel structure, but the amount of carbon steel will most typically be much greater than the amount of stainless steel, and the section loss in the carbon steel structure may be tolerable. If not, insulation kits should be used on the bolts to prevent section loss on the carbon steel members.
An aluminum cable tray is supported from a galvanized steel beam in an electrical switchyard.	If there is potential for moisture in this condition and chlorides are present, the aluminum may experience some section loss. If this is of concern, the materials should be isolated. In general atmosphere, galvanic corrosion between these materials will not typically occur.
A zinc-coated, carbon steel Unistrut member is welded to a stainless steel member to support a bin that will be exposed to seawater.	The Unistrut has a much more negative electrical potential and will likely corrode in this environment.
Aluminum fasteners are used in a steel bridge.	If chlorides from road salt are present, the aluminum fasteners will corrode significantly faster than the steel members, potentially resulting in premature collapse.
A carbon steel pipe is attached by a flange connection to a bronze pump body in a city water system with a high chloride content.	The carbon steel pipe will corrode and leak due to galvanic corrosion. A dielectric coupling should be used at the joint to prevent this from occurring.
A galvanized light-gauge carbon steel sloped cover plate is specified to prevent birds from perching on the bottom flange of an exterior beam. The plate is to be attached to a carbon steel beam with stainless steel fasteners.	As this situation occurs in an outdoor environment, the stainless steel fasteners will tend to cause section loss in the light-gauge galvanized steel plate. As the light-gauge material is thin, the amount of section loss may not be tolerable. Using a galvanized fastener will reduce the likelihood of galvanic corrosion.