

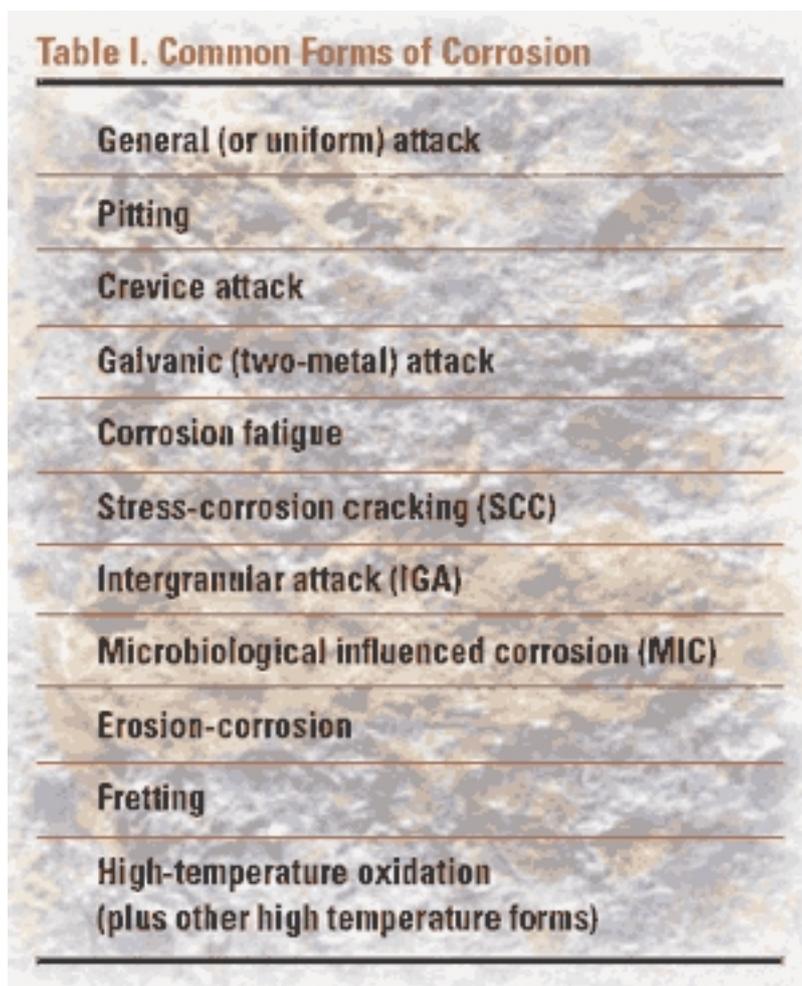
Battling A Killer: Corrosion Control Methods

Written by Gerald O. Davis, P.E. Davis Materials & Mechanical Engineering, Inc.
Thursday, 01 May 2008 00:00

Corrosion is always on the prowl, ready to take down your equipment, fixed and otherwise. Don't let this predator catch you off guard.

Metallic corrosion is a naturally occurring process that takes place at varying rates—depending on the specific combination of alloy and application conditions— unless there is intentional intervention to modify the situation. Corrosion is an inherent force like gravity. The laws of thermodynamics dictate that corrosion will occur in many situations. Principles of electrochemical kinetics define the rates at which those possible processes occur.

Among the many possible failure modes for physical assets in manufacturing operations, corrosion is one that has major economic impact. While this is primarily true for fixed equipment, corrosive attack also can cause or contribute to failures in rotating equipment.



The image shows a table titled "Table I. Common Forms of Corrosion" with a background of a rusted metal surface. The table lists eleven types of corrosion, each in a separate row separated by a horizontal line. The text is bold and black.

Table I. Common Forms of Corrosion
General (or uniform) attack
Pitting
Crevice attack
Galvanic (two-metal) attack
Corrosion fatigue
Stress-corrosion cracking (SCC)
Intergranular attack (IGA)
Microbiological influenced corrosion (MIC)
Erosion-corrosion
Fretting
High-temperature oxidation (plus other high temperature forms)

Although corrosion analysis and control closely depends on knowledge of metallurgy, that is just one starting point. Frequently, the effective choice and use of the alternative corrosion-control methods also draws on knowledge from the fields of chemistry and mechanical and electrical

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engineering. Complicating things is the fact that corrosion comes in several distinct forms (see Table I).

Rational decision-making regarding corrosion control is best done when the total life-cycle cost of each alternative is clearly defined. Often, the values of future costs and their timing depend on best-available estimates. Then, the financial techniques of discounted cash flow analysis should be applied. Hopefully, it is now well known that considering initial cost as the only criterion for choosing among corrosion-control measures for long-term use makes no practical sense. This is especially true when the cost of lost production during an unplanned shutdown as a result of corrosion failure is massive relative to the initial costs of each alternative. The details of this aspect of corrosion-control decisions are not considered here, but such analyses are essential. The four primary areas of corrosion control are:

- Material selection
- Coatings
- Cathodic Protection
- Chemical Inhibitors

In addition, there are several specific actions that can be applied in particular circumstances to help with corrosion problems. (Some of these are listed with brief comments at the end of this article.)

The recommended way to start this decision process is to first evaluate what the most probable form(s) of failure are likely to be—either due to corrosion or something else. The better we initially can estimate what failure mode is most probable, the better we can make provisions to stop or minimize its effects in service. For example, if the given equipment is known to require a high resistance to wear to prevent loss of function in the application, but there also is a possibility of corrosion, addressing the more pressing wear issue will take priority. In another case, one form of corrosion may be much more likely than the others. Thus, attention to that form of attack is emphasized first—but without ignoring the other possibilities.

Clearly, there are many ways to address the problem of in-service equipment failures. When it comes to corrosion-control methods, there are numerous options to review. Awareness of the major alternatives is an important first step.

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Material selection

The control method here is based on the inherent levels of corrosion resistance of the candidate alloys in the given environmental conditions.

To make the materials choice, the decision maker must attempt to know—to the greatest extent possible—the general chemical make-up and/or the concentration of the corrosive medium, as well as other variables important to corrosion. The latter may include the presence and concentrations of trace elements in the general medium, e.g., chloride ions or oxygen or other oxidizing components such as cupric or ferric ions, the maximum operating temperature, the flow velocities, the level of both applied and unavoidable residual stresses and whether the applied stresses are static or cyclic. The possibilities of “worse case” variations in operating conditions due to process upsets and start-up and shutdown periods must also be considered. Other factors include how long the selected material must provide useful service and whether periodic preventative maintenance monitoring can or will be done over time.

Examples of good versus poor material selections are reflected in the following:

Good...

- Mild steel for an above-ground storage tank (AST) for very concentrated sulfuric acid at ambient temperature
- Titanium alloys for superior resistance to seawater
- Commercially pure nickel (Nickel 200) and nickel-molybdenum alloys for good resistance to sodium hydroxide (NaOH) and hydrochloric acid (HCl), respectively

Poor...

- Copper alloys in ammonia or amines (SCC is likely)
- Mild steel in dilute sulfuric acid (rapid, general corrosion will occur)
- Type 316L stainless steel instead of Type 304L for a welded nitric acid tank (the molybdenum in the 316L degrades its resistance in strongly oxidizing acids such as nitric)

Coatings

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Most coatings—but not all—function primarily by providing a barrier between the corrosive medium and the substrate metal below. This category of corrosion control is the most widely used.

There are several different types of coatings, e.g., organic and inorganic paints and primers, galvanized coatings on steel and anodization on aluminum alloys. The many varieties of paints and primers get the most widespread use. Among these three examples, only galvanized steel provides corrosion control primarily by the process of sacrificial anode, cathodic protection (CP). CP is described below.

Many coating specialists advocate a systems approach for the use of paints and primers. This means the finished protective coating is considered as a synergistic whole where each part has an important but separate role in achieving success. Generally, a good system will consist of clear specifications, excellent preparation of the substrate surface, application of a primer, application of a top coat and competent field inspection at all stages of the process. It is widely agreed that surface preparation is—by far—the most important factor in achieving success.

It is always wise to spend more and achieve an excellent job of surface preparation, even if the top coat selected may be compromised. A well-prepared substrate is most important because it provides a base for good adhesion of either the primer (if one is used) or the top coat. Adhesion of the coating is critical.

Cathodic protection

Aqueous metallic corrosion always involves a flow of electrical current through the corrosive medium (known as the electrolyte) between the anodic portions of the exposed metal surface and the cathodic portions of that surface. The rate of corrosion is directly proportional to the rate of this current flow. The CP method functions by supplying a counteracting external current to greatly lessen the rate of corrosion that would otherwise occur. This external current changes the exposed surface being protected so that it becomes essentially all cathodic where little or no corrosion occurs. The anodic reaction then occurs on nearby installed anodes that supply the counteracting current.

There are two types of CP. One is sacrificial anode (or galvanic) CP, in which the current-supplying anodes are consumed over a period of years, but in the process the metallic asset is protected. The second type is impressed current cathodic protection (ICCP). Here the anodes are not consumed but they act to transfer DC current to protect the asset. Current is

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supplied to the anodes from an AC to- DC current rectifier that must be connected to an AC electric power source. Each method has advantages and disadvantages depending on the specific application.

CP is very frequently used in conjunction with a coating. This greatly decreases the amount of current required for protection. Therefore, sacrificial anodes last much longer or the amount of power consumption required in an ICCP system is much less. Federal law commonly requires the use and regular monitoring of coated CP systems for underground metallic pipelines and storage tanks used to handle hazardous fluids.

CP is used most often to protect underground metallic structures from soil corrosion. However, it is also applied to protect external tank bottoms in ASTs, for the water boxes of surface condensers used on large steam turbines and for the steel hulls of marine vessels.

Chemical inhibitors

Corrosion inhibitors are organic or inorganic chemicals that are added in small quantities to a corrosive medium so that the rate of corrosion of exposed metal is significantly reduced. There are many types and they function by several mechanisms. While inhibitors are commonly used in cooling water systems and in boiler feed water to steam boilers, they also are used with acid solutions. Vapor phase inhibitors often are included inside shipping containers for equipment to prevent atmospheric rust during prolonged shipment and storage periods.

Many inhibitors function in liquid systems by precipitating out of solution and forming an insoluble, microscale barrier film on the metal surfaces being protected. Thus, they act by retarding the anodic, the cathodic or (most effectively) both of these corrosion reactions on the metal. Examples of this type are certain alcohols, amines, sulfur compounds and phosphates.

Another class of inhibitors is known as oxidizers or passivators. They function by affecting the cathodic reaction and changing the electrochemical corrosion potential of the exposed metal so that it is in a low corrosion- current region. Traditional examples of this type are chromates and nitrites, but these have environmental problems. An alternative is to use molybdates.

Inhibitors known as oxygen scavengers react with residual oxygen in boiler feed water (after mechanical oxygen separation has been applied) to negate oxygen pitting of steel boiler

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components. Examples of this type inhibitor are sodium sulfite and hydrazine.

Certain cautions apply in the use of inhibitors. Typically, they are economically feasible (for liquid applications) only in recirculating systems and not for once-through systems. Because there is such a wide range of inhibitors, selection can be complex. The means of injecting the chosen inhibitor and monitoring its concentration throughout the system often is critical. The classic example of the importance of this relates particularly to oxidizing (or passivating) inhibitors. If concentrations of this type are too low within a given system then accelerated corrosion rates above expected rates with zero inhibitor present can occur. It should be clear that expert advice is needed to use inhibitors correctly.

Other corrosion-control actions

In certain situations one or more of the following approaches can have merit:

- Pay attention to design and fabrication details early in the specification process. These may include provisions for complete drainage; avoiding lap joints in plates and not using “skip” or tack welded joints so as to minimize crevice corrosion sites; making sure electrical insulators are in place between all unavoidable dissimilar metal contacts and if dissimilar metals must be in electrical contact, getting a favorable area ratio by making the more noble (cathodic) metal smaller in area versus the area of the active (anodic) metal.
- Evaluate flow velocities carefully. Too-high velocities can cause erosion-corrosion, and “dead legs” in piping encourage MIC, pitting or crevice attack.
- In rotating equipment, pay special attention to factors related to failure by fatigue, e.g., sharp radii, poor surface finish and castings defects. Depending on the given material and conditions, most realworld fatigue has at least some corrosion involved. “Pure” mechanical fatigue only occurs in a nearvacuum environment. Actual plant conditions, e.g., humid air or worse conditions, encourage corrosion fatigue and contribute to shortened equipment life.
- Always consider the need for post-weld stress relief heat treatment. Residual weld stresses can promote as much or more SCC than applied stresses in equipment.
- Consider the use of polymeric materials where required mechanical properties and maximum service temperatures permit.
- For metal plate applications, use a thin sheet of higher alloyed material (for corrosion resistance) metallurgically bonded to a mild steel substrate (for strength).
- Add a corrosion allowance during the design of pressure vessels, i.e., extra plate or head thicknesses in ASME code-built pressure vessels, beyond the thickness needed for strength if only general corrosion is expected. Localized forms of corrosion like pitting and SCC penetrate metal in erratic steps, which likely will preclude the value of this approach.

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Conclusion

Corrosion—in its several forms—is the cause of much lost revenue due to failures of equipment in many industrial applications. There are many facets to corrosion control and knowledge in several areas is required to effectively fight this predator. It is always advisable to obtain objective, competent advice when seeking the optimal choice among available corrosion-control alternatives. The references cited at the end of this article are good sources for additional information. **MT**

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