



Corrosion can be defined as the destruction of a metal by chemical or electrochemical reaction with its environment. The cost of corrosion is phenomenal. Recent estimates indicate that over \$70 billion is spent in the United States annually as a result of corrosion.

Corrosion is an electrochemical process in which the anode, where the dissolution is occurring, is separated by a physical distance from the cathode where a reduction reaction is occurring. A potential difference exists between these sites, and current flows through the solution from the anode to the cathode. This is accompanied by the flow of electrons from the anode to the cathode through the metal. The figure below illustrates this process. The typical anodic reaction is  $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$ . This reaction is accompanied by the reaction  $\text{Fe}^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2$ . The ferrous hydroxide, black rust, then combines with oxygen and water to produce ferric hydroxide,  $\text{Fe}(\text{OH})_3$ , common red rust.

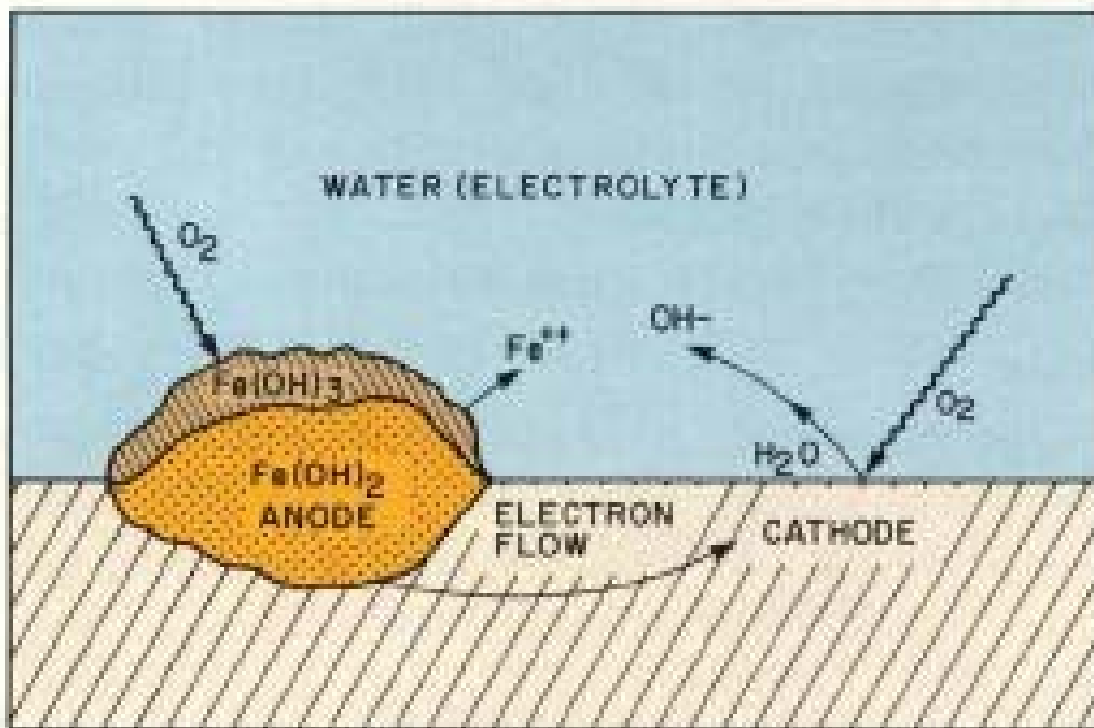


Figure 24-1. Classic corrosion cell.

The primary cathodic reaction is  $\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2OH^-$ . Oxygen reaches the surface by diffusion as indicated by the wavy lines in the illustration. This oxygen reduction reaction controls the rate of corrosion; the rate of diffusion is usually the limiting factor.

Another important cathodic reaction is  $2H^+ + 2e^- \rightarrow H_2$ . At neutral or higher pH, the concentration of  $H^+$  ions is too small for this reaction to significantly contribute to the overall corrosion rate. But as pH decreases, this reaction becomes more important until, at a pH of about 4, it becomes the predominant cathodic reaction.

An understanding of corrosion is fundamental and essential to prevention of chemical and electrochemical deterioration. The following is a list of the different types of corrosion and their characteristics.

### **DIRECT ATTACK**

This is probably the most common type of corrosion. It can occur when oxygen, water, ozone, salts, or many other substances chemically react with components. Occasionally, this can be beneficial; aluminum and stainless steel can rapidly form a thin, tight surface oxide layer which swiftly inhibits further oxidation or other degradation. Most steels, however, form porous oxide layers so that the environment is not excluded, and attack continues.

### **FILIFORM CORROSION**

This is a specialized form of Direct Attack characterized by randomly distributed hairlines of corrosion under coated surfaces. The process is sometimes referred to as “underfilm corrosion” and “filamentary corrosion.”

### **GALVANIC CORROSION**

An electrochemical reaction occurring where a metal contacts a more noble metal in the presence of some type of corroding medium or electrolyte. The contact must be good enough to conduct electricity and both metals must be connected by the solution. The driving force for galvanic corrosion is the potential difference that develops between the two metals. The difference increases as the distance between them on the galvanic series increases. The list below shows a galvanic series for some commercial metals and alloys. When metals from the series are connected, the corrosion rate of the more active (anodic) metal increases and the corrosion rate of the more noble (cathodic) metal decreases.

#### **MORE CORROSIVE - (Anodic, Least Noble)**

<ul style="list-style-type: none"><li>• Magnesium</li><li>• Magnesium Alloys</li><li>• Zinc</li><li>• Aluminum 2S</li></ul>	<ul style="list-style-type: none"><li>• Nickel</li><li>• Inconel</li><li>• Hastelloy A</li><li>• Hastelloy B</li></ul>
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<ul style="list-style-type: none"> <li>• Cadmium</li> <li>• Aluminum 17ST</li> <li>• Steel or Iron</li> <li>• Cast Iron</li> <li>• Chromium-Iron</li> <li>• Nickel Resist</li> <li>• Hastelloy C</li> <li>• Lead-Tin Solders</li> <li>• Lead</li> <li>• Tin</li> </ul>	<ul style="list-style-type: none"> <li>• Brasses</li> <li>• Copper</li> <li>• Bronzes</li> <li>• Copper-Nickel Alloys</li> <li>• Titanium</li> <li>• Monel</li> <li>• Silver Solder</li> <li>• Silver</li> <li>• Graphite</li> <li>• Gold</li> </ul>
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LEAST CORROSIVE - (Cathodic, Most Noble)

### **HYDROGEN EMBRITTLEMENT**

This is often found after pickling steel. Developing hydrogen atoms can either combine into molecules of hydrogen gas or diffuse into the metal. When these diffused atoms collect in voids or cracks in the metal, they form hydrogen gas and exert internal pressure which can increase until it exceeds the matrix yield strength. Hydrogen embrittlement is most commonly relieved by post-baking parts as soon as possible after plating.

### **FRETTING CORROSION**

This is normally experienced when there is a slight relative motion at the interface of two materials (mechanical abrasion). It typically occurs at close-fitting, highly stressed interfaces. Though it can take place in all metals, aluminum, stainless steel, and titanium alloys are most susceptible. These metals depend on tight oxide surface film to inhibit continued corrosion. With rapid movement under pressure, interface oxides are removed, and continual rapid oxidation occurs, abetted by the debris formed. With steel, only oxygen appears necessary for fretting. Moisture does not seem to increase fretting corrosion; actually, it tends to slow it.

### **STRESS CORROSION**

This corrosion takes place when tensile stress and corrosion produce greater damage than either applied separately. Failure can often be catastrophic. Stress corrosion is usually highly localized and generally appears in the form of cracks along grain boundaries.

### **CAUSTIC EMBRITTLEMENT**

This is a form of stress corrosion which occurs in mild steels under stress and when exposed to high temperature and to a caustic solution. The corrosion often appears in the form of intergranular attack. Reducing internal stresses by shot peening or other mechanical methods will reduce the likelihood of damage.

## **CREVICE CORROSION**

A form of localized attack which can occur at crevices initially designed into the product or where an accumulation of residue or foreign material exists.

## **CORROSION FATIGUE**

The process by which metals fail under repeated cycling at stress substantially below the metal's nominal strength in a chemically corrosive environment. Corrosion fatigue may be described as a combination of corrosion and normal fatigue causing further reduction in fatigue resistance.

## **INTERGRANULAR CORROSION**

The attack of certain metals along their grain boundaries. The boundaries become small anodic areas electrically connected with the larger cathodic grains, resulting in severe intergranular corrosion under many circumstances.

## **DEZINCIFICATION**

A corrosion process that removes zinc from an alloy. It generally occurs with alloys made up of elements widely separated in electro-chemical activity. A good example occurs in brass when zinc is removed, leaving behind a porous copper structure lacking the strength of the original brass. Selective leaching of zinc can occur in other alloys, again with loss of the original material's properties.

## **GRAPHITIZATION**

A type of corrosion that usually occurs in gray cast iron. The graphite is cathodic with respect to iron and the presence of moisture creates a galvanic cell. Resultant selective corrosion leaves a porous mass of graphite, with visual inspection often not showing the true extent of damage.

## **EROSION CORROSION**

This corrosion is experienced where there exists a relative fluid movement over a metallic surface. Both mechanical and corrosive failures are experienced. Aluminum and stainless steels are highly susceptible to this form of attack, which removes the protective oxide film from the base metal. It can be localized or fairly uniform depending on the fluid's abrasive action with respect to various surface regions. Metals which rely on a protective film are most susceptible, but all metals can corrode in this manner. Proper alloy selection can be very important in reducing attack.

## **CAVITATION EROSION**

This occurs where extreme pressure changes and rapid fluid flow typical of turbulent solutions cause formation and collapse of bubbles at the metal surface. Pitting and non-uniform depressions in the metal surface are characteristic. Proper material selection and protective coatings are best guards. Generally, stainless steels and aluminum bronzes have good resistance to cavitation erosion.

## **PITTING**

One of the most destructive forms of corrosion and also one of the most difficult to predict in laboratory tests. Once a pit is formed, the solution inside it is divorced from the bulk environment and becomes increasingly corrosive with time. The high corrosion rate in the pit produces an excess of positively charged metal cations which attracts chloride anions. In addition, hydrolysis produces  $H^+$  ions. The increased acidity and concentration within the pit promote even higher corrosion rates and the process becomes self-sustaining. All the local surface differences discussed before can be sites for pit initiation.

## **CONCLUSION**

Preventing corrosion in industrial applications is a problem to which much research has been devoted. Effective anti-corrosion measures have been developed which can be applied in most instances at reasonable cost. Today, the expense of corrosion prevention is minor compared with the cost of equipment replacement, downtime, and production losses.