

Corrosion of Metals

- Corrosion is defined as the destructive and unintentional attack on a metal;
- It is electrochemical and ordinarily begins at the surface.
- The consequences of corrosion are all too common. Familiar examples include the rusting of automotive body panels and radiator and exhaust components.
- Corrosion processes are occasionally used to advantage. For example, etching procedures, use the selective chemical reactivity of grain boundaries or various microstructural constituents.

FORMS OF CORROSION

It is convenient to classify corrosion according to the manner in which:

- Uniform
- Galvanic
- Crevice
- pitting
- intergranular
- Selective leaching
- Erosion–corrosion, and
- Stress corrosion.

We have elected to discuss the topic of hydrogen embrittlement in this section. Hydrogen embrittlement is, in a strict sense, a type of failure rather than a form of corrosion; however, it is often produced by hydrogen that is generated from corrosion reactions.

Uniform Attack

Uniform attack is a form of electrochemical corrosion that occurs with equivalent intensity over the entire exposed surface and often leaves behind a scale or deposit. In a microscopic sense, the oxidation and reduction reactions occur randomly over the surface. Familiar examples include general rusting of steel and iron and the tarnishing of silverware.

Galvanic Corrosion

Galvanic corrosion occurs when two metals or alloys having different compositions are electrically coupled while exposed to an electrolyte. The less noble or more reactive metal in the particular environment experiences corrosion; the more inert metal, the cathode, is protected from corrosion. As examples, steel screws corrode when in contact with brass in a marine environment, and if copper and steel tubing are joined in a domestic water heater, the steel corrodes in the vicinity of the junction.

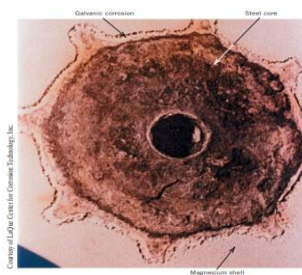


Figure 17.14 Photograph showing galvanic corrosion around the inlet of a single-cycle bilge pump that is found on fishing vessels. Corrosion occurred at the interface between a magnesium shaft and a steel core around which the magnesium was cast.

Figure 17.15 On this plate, which was immersed in seawater, crevice corrosion has occurred at the regions that were covered by washers. (Photograph courtesy of LaQue Center for Corrosion Technology, Inc.)



Crevice Corrosion

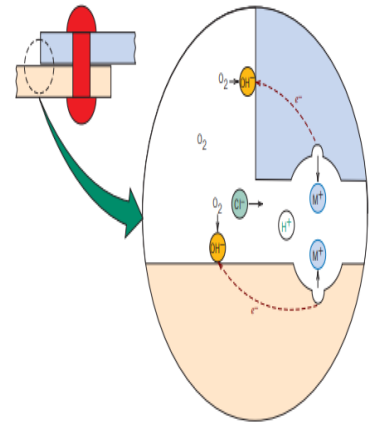
Electrochemical corrosion may also occur as a consequence of concentration differences of ions or dissolved gases in the electrolyte solution and between two regions of the same metal piece. For such a concentration cell, corrosion occurs in the locale that has the lower concentration. A good example of this type of corrosion occurs in crevices and recesses or under deposits of dirt or corrosion products where the solution becomes stagnant and there is localized depletion of dissolved oxygen. Corrosion preferentially occurring at these positions is called crevice corrosion (Figure 17.15). The crevice must be wide enough for the solution to penetrate yet narrow enough for stagnancy; usually the width is several thousandths of an inch. Figure 17.16 shows that after oxygen has been depleted within the crevice, oxidation of the metal occurs at this position.

Pitting

- Pitting is another form of very localized corrosion attack in which small pits or holes form.
- They ordinarily penetrate from the top of a horizontal surface downward in a nearly vertical direction.
- The mechanism for pitting is probably the same as for crevice corrosion.

Figure 17.16

Schematic illustration of the mechanism of crevice corrosion between two riveted sheets.



- Oxidation occurs within the pit itself, with complementary reduction at the surface. It is supposed that gravity causes the pits to grow downward, the solution at the pit tip becoming more concentrated and dense as pit growth progresses.
- A pit may be initiated by a localized surface defect such as a scratch or a slight variation in composition.

Intergranular Corrosion

- Intergranular corrosion occurs preferentially along grain boundaries for some alloys and in specific environments.
- A macroscopic specimen disintegrates along its grain boundaries.
- This type of corrosion is especially prevalent in some stainless steels.
- Ex: when heated to temperatures between 500°C and 800°C (950°F and 1450°F) for sufficiently long time periods, these alloys become sensitized to intergranular attack.
- Intergranular corrosion shown in Figure 17.19. Stainless steels may be protected from intergranular corrosion by the following measures: (1) subjecting the sensitized material to a high-temperature heat treatment in which all the chromium carbide particles are re-dissolved, (2) lowering the carbon content below 0.03 wt% C so that carbide formation is minimal, and (3) alloying the stainless steel with another metal such as niobium or titanium, which has a greater tendency to form carbides than does chromium so that the Cr remains in solid solution.



Figure 17.17 Pitting of a 316L stainless steel pipe surface by a phosphate solution. (Photograph courtesy of Rick Adler/Adler Engineering LLC of Wyoming USA)

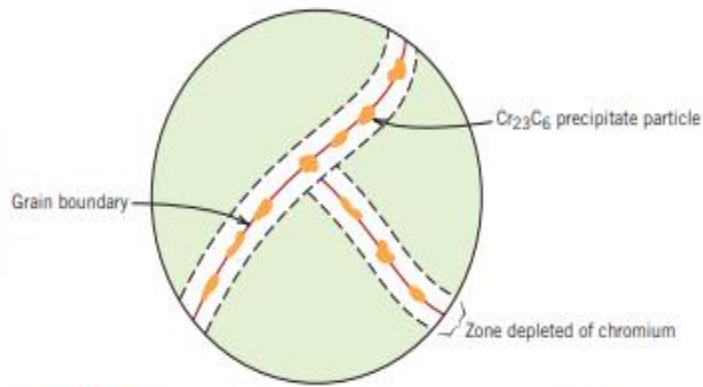


Figure 17.18 Schematic illustration of chromium carbide particles that have precipitated along grain boundaries in stainless steel, and the attendant zones of chromium depletion.

Selective Leaching

- Selective leaching is found in solid solution alloys and occurs when one element or constituent is preferentially removed as a consequence of corrosion processes.
- The most common example is the dezincification of brass, in which zinc is selectively leached from a copper–zinc brass alloy.
- The mechanical properties of the alloy are significantly impaired because only a porous mass of copper remains in the region that has been de-zincified. In addition, the material changes from yellow to a red or copper color. Selective leaching.

Erosion–Corrosion

- Erosion–corrosion arises from the combined action of chemical attack and mechanical abrasion or wear as a consequence of fluid motion.
- Virtually all metal alloys, to one degree or another, are susceptible to erosion–corrosion.
- It is especially harmful to alloys that passivate by forming a protective surface film; the abrasive action may erode away the film, leaving exposed a bare metal surface. If the coating is not capable of continuously and rapidly re-forming as a protective barrier, corrosion may be severe.
- Relatively soft metals such as copper and lead are also sensitive to this form of attack.

- Usually it can be identified by surface grooves and waves having contours that are characteristic of the flow of the fluid.

- The nature of the fluid can have a dramatic influence on the corrosion behavior (fluid velocity bubbles and suspended particulate).

- EX: in piping, especially at bends, elbows, and abrupt changes in pipe diameter, Propellers, turbine blades, valves, and pumps.

- One of the best ways to reduce erosion–corrosion is :

1- Change the design to eliminate fluid turbulence and impingement effects.

2- Other materials may also be used that inherently resist erosion.

3- Removal of particulates and bubbles from the solution lessens its ability to erode.

Stress Corrosion

- Stress corrosion results from the combined action of an applied tensile stress and a corrosive environment;

- Small cracks form and then propagate in a direction perpendicular to the stress , with the result that failure may eventually occur.

- For example, most stainless steels stress corrode in solutions containing chloride ions, whereas brasses are especially vulnerable when exposed to ammonia.

- A photomicrograph showing in Figure 17.22 is an example of intergranular stress corrosion cracking in brass.

- Also, gaseous and solid corrosion products that are entrapped internally can give rise to internal stresses.

- Probably the best measure to take to reduce or completely eliminate stress corrosion is to lower the magnitude of the stress. And substituting a more embrittlement-resistant alloy.

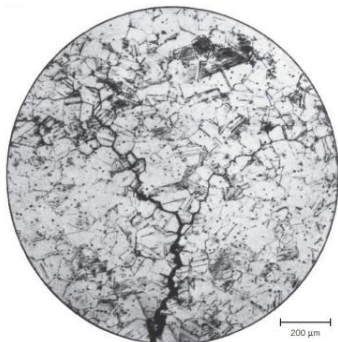


Figure 17.22 Photomicrograph showing intergranular stress corrosion cracking in brass. (From H. H. Uhlig and R. W. Revie, *Corrosion and Corrosion Control*, 3rd edition, Fig. 5, p. 335. Copyright 1985 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)



Figure 17.20 Impingement failure of an elbow that was part of a steam condensate line. (Photograph courtesy of Mars G. Fontana. From M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright © 1986 by McGraw-Hill Book Company. Reproduced with permission.)

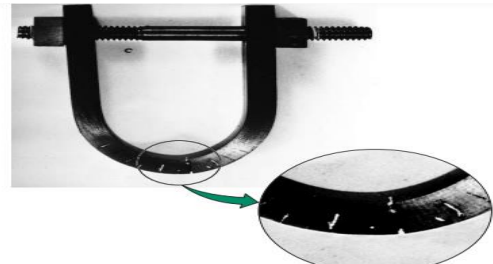


Figure 17.21 A bar of steel bent into a horseshoe shape using a nut-and-bolt assembly. While immersed in seawater, stress corrosion cracks formed along the bend at those regions where the tensile stresses are the greatest. (Photograph courtesy of F. L. LaQue. From F. L. LaQue, *Marine Corrosion, Causes and Prevention*. Copyright © 1975 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)