

Protecting Fasteners from Corroding

Part 1: Basics of Corrosion and Protection Mechanisms

by Laurence Claus

The man walked to his tool box, selected the right sized socket and returned to the piece of machinery he was trying to repair. He stared for a moment at the nut he was trying to loosen. It was badly corroded but he had done this many times before. Carefully seating the socket fully on the nut he began to apply pressure. At first nothing happened but then he felt a tiny change in the resistance, reinvigorating his incentive to keep pushing on the bar. Just as he thought he had given it his all, a resounding loud snap occurred catapulting him and his tools forward as his efforts were no longer restrained by the once stubborn but now broken bolt and nut. Crashing into the floor, he yelped in pain and cursed his misfortune.

For many of us the story of this unfortunate mechanic could be one of our own. Many of us have encountered a bolt, nut, or screw stubbornly corroded into place by the rigors of time and use. It is for this reason that fastener designers take great care when considering their product's environment and choosing a material, plating or coating for the fasteners to protect them from deteriorating and reducing the life of their product.

This first installment in a series on protective finishes for fasteners will introduce the different types of corrosion that may be experienced by fasteners and the mechanisms that protective coatings and platings employ to protect them.

What is Corrosion?

Corrosion is the destructive alteration of metal by chemical or electrochemical reaction with its environment. Chemical attack can occur directly when a metal fastener comes in contact with a corroding chemical, such as occasionally happens with automotive battery hardware located on or near a leaking car battery. More often, however, fastener corrosion occurs as the result of a more indirect electrochemical reaction. Rusting of steel and galvanic corrosion are examples of this mechanism.

Fastener corrosion is a little like tooth decay. It may begin very modestly but often accelerates and always has the effect of reducing the mechanical integrity of the joint in some fashion. In the most common scenario a fastener component begins to corrode, slowly reducing the mechanical integrity of the fastener until it no longer maintains the requisite strength to withstand the loads or demands being placed upon it and fails in overload. Although this is the most common progression of corrosion with fasteners, galvanic action can also corrode the surrounding joint material. Two other corrosion induced failures include stress corrosion, such as hydrogen embrittlement, and corrosion fatigue, where the site of the corrosion initiates a crack that progresses into a fatigue failure.

Although it is rare, fastener materials that have not been properly selected for their service environment can result in direct chemical attack. This occurs when the fastener material is soluble in the corroding medium, such as when a plain steel bolt comes in contact with hydrochloric acid. Some examples of very harsh environments where designers have to keep this in-mind include petrochemical plants, sour gas oil wells, pulp and paper mills, and certain food processing plants. When these environments are known or predicted, it is important that the designer choose a fastener material that is impervious to the solvent, perhaps stainless steel or a nickel alloy. Another strategy might be to choose a coating that is impervious and can withstand contact with the solvent.

Much more commonly, corrosion stems from an electrochemical mechanism. This corrosion occurs as a result of microscopic chemical reactions that are catalyzed by tiny, self-generated electrical current flow. For these processes to initiate there must be an electrode consisting of an anode (positively charged area) and a cathode (negatively charged area), an electrolyte (electrically conducting liquid or substance), and an electrical potential difference to trigger the beginning of a current flow and, thus, the start of the reaction.



Fig. 1

Rusting of Steel:

Rusting of steel is perhaps one of the simplest electrochemical corrosion reactions. When a droplet of water lands on bare steel there are differences in the electrical state produced at the interface of the electrode (the bare steel) and the electrolyte (the droplet of water.) This difference in state triggers current flow, which starts the process. In the case of rusting steel, an oxidation reaction occurs at the anodic area and releases an iron ion into the electrolyte. Likewise, a reduction reaction at the cathodic region forms hydroxide ions from atmospheric oxygen that surrounds the water droplet. A third reaction now occurs inside the water droplet (the electrolyte) and the iron and hydroxide ion combine to form iron oxide or rust. The rust precipitates out onto the surface of the part. If the part stays moist, this process continues and parts can quickly be consumed with rust. The longer this is allowed to occur the more extensive those parts can be deteriorated. Fig. 1 illustrates a badly rusted fastener.



Galvanic Corrosion:

Another type of electrochemical corrosion is Galvanic Corrosion or what is often simply referred to as dissimilar metal corrosion. Like any electrochemical corrosion mechanism there must be an anode, cathode, electrolyte, and enough electrical potential differential to trigger current flow. The current is triggered when two different metals with different electrical potentials are put in contact with one another. When the two contacting materials are in the presence of an electrolyte and have a large enough electrical potential difference, an electrical current flow is triggered between the material acting as the anode and the one acting as the cathode. In this process the material acting as the anode is stripped of its atoms and begins to corrode. The stronger the galvanic coupling the faster and more aggressive this form of corrosion will be.

Fig. 2 illustrates the Galvanic Series Table and can be used by fastener engineers and designers to minimize the risks of galvanic corrosion. In essence the two ends of this chart represent materials that behave like the anode (corroded material) or the cathode (protected material). The position on this chart represents the material's electrical potential. The further apart two materials are on this chart the stronger a galvanic coupling of the two will be if they are brought into contact with one another. For example, the pairing of Magnesium and Platinum would not be a good one as they are at the far opposite extremes of the chart. However, pairing materials with similar electrical potentials (as noted by materials located in the same colored bands) may trigger little or no galvanic reaction.

Fig. 2 Galvanic Series Table

Anode (Corroded End)
Magnesium
Magnesium Alloys
Zinc
Aluminum
Cadmium
Steel and Iron
Cast Iron
Lead
Tin
Nickel
Inconel
Hastelloy
Brass
Copper
Bronze
Monel
Type 304 Stainless (passivated)
Type 316 Stainless (passivated)
Silver
Titanium
Graphite
Gold
Platinum
Cathode (Protected End)

The extent of galvanic corrosion will depend on three things:

- The magnitude of difference in electrical potentials – the further apart on the Galvanic Series Table two materials are the greater the anticipated extent of galvanic corrosion. For example an aluminum part coupled with a Type 316 stainless steel part is expected to experience considerably more effects of galvanic corrosion than the coupling of identical components made of steel and tin.
- The strength of the electrolyte- the more minerals (ions) in an electrolyte the better it is able to conduct electricity. Therefore, salt water is a much stronger electrolyte than deionized water. The stronger the electrolyte the more quickly galvanic corrosion will occur.
- The relative sizes of the contacting areas- the larger the cathode is relative to the anode, the faster and more severe the galvanic corrosion will be. Take for example placing one small aluminum fastener in a large stainless steel plate. Clearly these two materials are separated far apart on the Galvanic Series Table. The aluminum fastener is the anode and is small compared to the cathodic stainless steel plate. In this case, in the presence of an electrolyte, the aluminum fastener would be expected to corrode quickly. Now flip this scenario around and make the single small fastener stainless steel and the plate aluminum. There is still a dissimilar coupling which will trigger galvanic corrosion, but the size of the cathode relative to the anode is quite small so that the only corrosion we might expect would be localized to just around the contact edges of the fastener with the plate.

Fretting Corrosion:

One of the few corrosion mechanisms that occasionally impacts fasteners that is not chemical or electrochemical in nature is fretting corrosion. Fretting corrosion results when highly loaded contacting surfaces rub against one another abrading the protective layer away, and in the case of materials that rely on protective oxide films prevent their regeneration. Fasteners made of Stainless Steel, Aluminum, and Titanium are particularly susceptible to fretting corrosion because they rely on protective oxides. Areas where this may be of concern are in mating threads and the bearing surfaces underneath the nut or bolt heads.

Crevice Corrosion:

Perhaps one of the most insidious forms of corrosion is Crevice Corrosion. Crevice Corrosion is a localized electrochemical form of corrosion initiated when different areas of metal are exposed to different concentrations of the same electrolyte. This occurs in crevices, internal corners, low points and openings, or any place that moisture, dirt, and other foreign matter can accumulate. Because the corrosion may be acting over a very localized section of the fastener, the resulting environment can be quite harsh and result in extreme, and often unnoticed, damage. Additionally these localized areas of corrosion can generate a significant amount of atomic hydrogen, which can be absorbed into a part and lead a susceptible one to a hydrogen assisted stress corrosion failure.



I recall working on a case a number of years ago where a fastener was threaded into the end of a shaft. The manufacturer cleaned the shaft prior to assembly. During one production run they did not do a good job extracting the cleaning fluid from the threaded hole. When the fastener was threaded in, the presence of the cleaning fluid, a strong electrolyte, triggered a crevice corrosion event.

Pitting Corrosion:

Pitting corrosion is a highly localized form of corrosion at the metal's surface where a microscopic pit forms and grows through subsequent attack into a deeper and more noticeable defect. The good news is that although pitting can be unsightly, it rarely threatens the mechanical integrity of the parts like other corrosion types do. The mechanism is a little bit complicated but essentially occurs when a very small area becomes oxygen starved and turns anodic. An electrochemical process is triggered, a pit forms, and often deepens as further attack occurs.

Protection Mechanisms:

Now that we have looked at the more predominant corrosion mechanisms in fasteners, how do fastener protection mechanisms work to protect parts from corrosion? In essence there are four protection mechanisms that can be employed singly or, perhaps, in combination.

- **Barrier-** A barrier mechanism is one that does exactly as the word describes. It creates a shield (or barrier) that acts to keep the corroding substances away from the base metal. This mechanism works well as long as the barrier stays intact. Corrosion begins as soon as the barrier wears away or is damaged and exposes what is underneath. Perhaps the most common example of barrier coatings are painted surfaces.
- **Sacrificial (Galvanic) -** A sacrificial mechanism is one that sacrifices itself before allowing base metal attack. Like barrier mechanisms, these are effective only to the point that the protective layer remains. As soon as it is used up and the base metal is exposed, corrosion will start. Zinc electroplating is a common example of a sacrificial mechanism.
- **Passivation-** The outer layer is made inert so that it protects the surface from corrosion reactions. Stainless steel is an excellent example of one that relies on a protective oxide to protect the part.
- **Self-healing-** Perhaps the best characteristic for a protective finish is to have self-healing properties. This simply means that the protective layer is able to repair itself if it is damaged. This mechanism is prized because it is not all that common, but very effective when it exists. Once again, austenitic stainless steel is an example of a self-healing finish.

In Summary:

Fasteners can be subject to a variety of different corrosion mechanisms. Designers must, therefore, understand what kind of corrosive circumstances their products might experience and take protective measures to either delay the inevitable or prevent it entirely. In the next segment in this series (Fastener World Magazine Jan. 2022 issue) we will look at electroplating and how it prevents fasteners from corroding. ■

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