FASTENER**FACTS**™

An Informational Series From All-Pro Fasteners

Fasteners & Corrosion

Avoiding Problems in Advance

INTRODUCTION

Each year, the effects of corrosion on public and private assets represents an equivalent cost of 3.4% of global GDP, according to estimates.[1] This staggering cost affects the infrastructure, energy, manufacturing, transportation, construction, marine, and service industries, costing manufacturers, operating companies, service providers, contractors, investors, engineers, designers, customers, taxpayers, and others involved in local, national, and global economies.

Corrosion engineers are engaged in the study and practice of corrosion management, providing guidance on the selection of cost-effective materials, coatings, and corrosion mitigation strategies. The work performed by these specialists helps to ensure the technical integrity of materials and installations. In determining appropriate materials, coatings, and corrosion management tactics, the specialist must assess each component of a system against a variety of factors, including environmental conditions, application requirements, estimated product/system lifetime, and available mitigation methods.

Fasteners – often the least expensive component in a system's design – deserve particular attention in that (a) their failure can lead to serious expense and performance issues affecting the entire installation, and (b) this failure can largely be avoided or mitigated through the proper selection of materials, coatings, and platings, to help ensure desired performance over the life of the installation.

This document will discuss some of the important considerations involved in the selection of fastener materials, designs, and coatings, in order to help design engineers, project managers, and purchasing personnel avoid potential problems that can result from fastener corrosion.

1 National Association of Corrosion Engineers (NACE)
NACE International has become the global leader in developing corrosion prevention and control standards, certification and education. NACE is a standards-writing organization accredited by the American National Standards Institute (ANSI).

ENVIRONMENTAL FACTORS

Environmental factors play an overriding role in the selection of materials and coatings to resist corrosion. A review of environmental factors is therefore critical to help avoid potential problems. This section discusses factors to consider in atmospheric, water, and soil environments.

Atmospheric Environments

Contaminants, humidity, wind or water currents, pH level, and temperature are all elements of atmospheric environments that should be considered in the design and selection of fastener products.

Contaminants

Rural environments are generally the least corrosive, with the principal corrodents being oxygen and moisture content. Urban environments, while similar to rural, may present sulfur dioxides and nitrous oxides from vehicle and domestic fuel emissions. Industrial environments may contain sulfur dioxides, chlorides, nitrates, and phosphates from processing facilities, as well as special instances of hydrogen sulfide, hydrogen chloride, and chlorine, which are highly corrosive to most metals.

Humidity and Rainfall

Humidity is a major factor in determining the potential for the corrosion of metals. This is because moisture provides the electrolyte that is required for corrosive processes to occur. In the absence of other electrolytes, the level of relative humidity required for corrosion to occur is 60%.

Wind

The corrosivity of atmospheric environments can be enhanced by wind, as it affects the distance and direction contaminants can be dispersed. Proximity to coastal waters and industrial sites can affect general corrosion rates.

Temperature

As environmental temperature increases, the potential for corrosion increases. Temperature can also affect the form of corrosion that occurs – as temperature changes, the type of corrosion may change from one form to another. High temperatures can even cause a form of corrosion in which gas becomes an electrolyte.

Water Environments

Water environments are divided into natural (fresh) water and seawater (salt) type environments. The factors that determine the corrosivity of water environments include water composition, salinity, pH level, temperature, water velocity, and biological organisms.

Water Composition

Water composition can vary widely, based on atmospheric materials and contaminants picked up from rainfall, soil, and man-made pollutants. Dissolved gases (primarily oxygen and sulfurous gases) and salts are the compounds representing the greatest corrosion risk in water environments. Oxygen is, by far, the biggest concern, with its greatest concentration on the surface of water and in the presence of algae.

pH Level

The normal pH level of water (both natural and seawater) ranges from 4.5 to 8.5. The rate of corrosion of certain metals increases in acidic water.

Temperature

As in atmospheric environments, higher water temperatures generally increase corrosion rates. Even though higher temperatures decrease oxygen solubility, they increase biological growth, which increases overall oxygen content.

Water Velocity and Agitation

Water velocity and agitation can both increase and decrease corrosion rates on certain metals. For most metals, there is a critical velocity beyond which serious corrosion occurs.

Biological Organisms

Certain biological organisms alter the composition of water, which may lead to increased or decreased corrosion rates. Some organisms increase oxygen or sulfide content, increasing the potential for corrosion.

Soil Environments

Factors contributing to the corrosivity of soil includes soil particle size, water, aeration, pH level, temperature, salt content, and biological activity.

Water

Soils comprised of large particles will retain less water and exhibit more oxygen content, thereby increasing the potential for corrosion. (Oxygen content is highest at or near the surface.)

pH Level

The pH level of soil is typically 5 to 8, a range in which corrosion rates are not significantly affected. However, acidic soils will increase corrosivity.

Salt

A soil's electrical resistivity provides a general indication of the potential for corrosion. (Lower resistivity signals higher corrosivity.) Salt content has an effect on corrosivity, with sulfites and chlorides being the most aggressive corrosive agents.

FORMS OF CORROSION AFFECTING FASTENERS

The majority of observed corrosion-related fastener problems are caused by well known, easily identifiable forms of corrosion. These include uniform and galvanic corrosion, as well as pitting corrosion, fretting fatigue, stress corrosion, erosion corrosion, and other forms. In specific environments (e.g., where specific chemicals are present in the atmosphere), lesser and more specialized forms of corrosion occur. This section will focus on the most common types of corrosion affecting fastener performance.

Uniform Corrosion

Uniform corrosion (also referred to as “general” corrosion and “general attack” corrosion) tends to develop uniformly over an exposed surface, resulting in the thinning of materials, until failure occurs. Uniform corrosion is dependent upon two factors: the composition of the material and the characteristics of the environment.

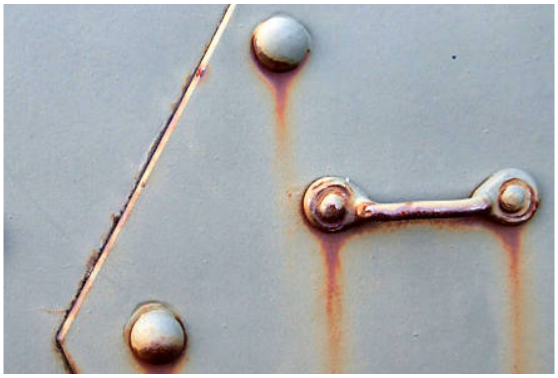
Uniform corrosion occurs due to an electro-chemical process that takes place on the surface of the material. During this process, anodes and cathodes are created that facilitate the corrosion process.

General corrosion occurs predictably. It is normally the result of placing inappropriate materials in corrosive environments.

MITIGATION TIP

To avoid and/or minimize uniform corrosion, material should be carefully evaluated to ensure that it is not susceptible (or is minimally susceptible) to corrosive potential in the environment.

Galvanic Corrosion



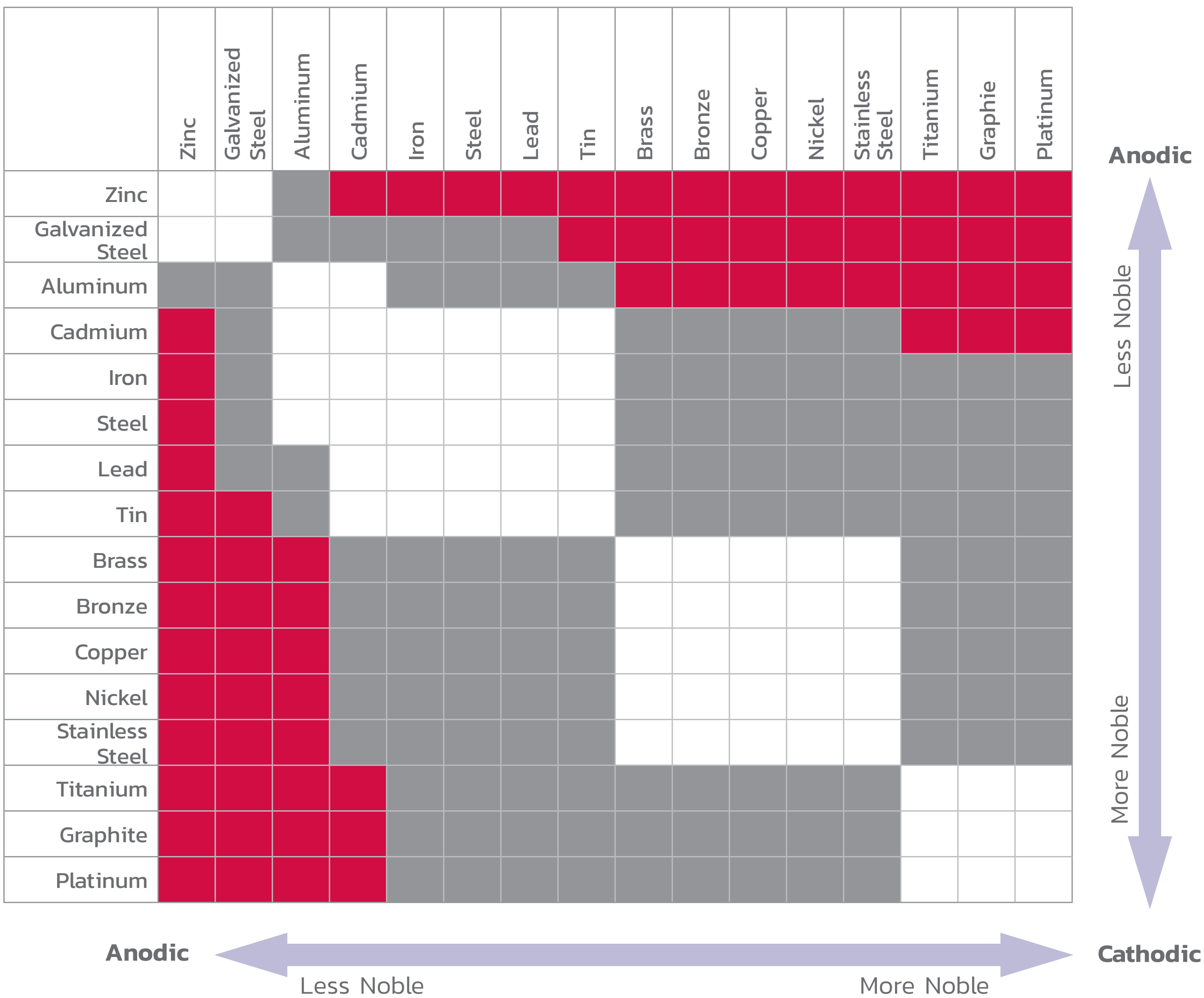
Galvanic corrosion is a process that occurs when two metals of differing electrical potentials are physically connected, or electrically connected through a conductive electrolyte such as rain-water or groundwater. An electrical current can be formed that attracts electrons away from the more active metal (anode), thereby causing corrosion, while boosting the corrosion resistance of the passive metal (cathode).

Galvanic corrosion is a major consideration in the selection of fastener materials to be used in a given application. Due to the fact that fasteners have a much smaller surface area than the materials they fasten, they are at the risk of rapid corrosion if subject to galvanic corrosion.

MITIGATION TIP

To minimize the risk of galvanic corrosion, the material selection process should ensure: (a) proper matching of the fastener material to the metal being fastened, and (b) use of metals that are sufficiently close on the Galvanic Series chart, so as not to cause the galvanic corrosion process to occur.

GALVANIC SERIES OF FASTENER METALS



O.K. to mix   Problematic   DO NOT mix

Consider the metals used in both the fastener system and in the metal surface to be fastened. Do not mix metals shown in the red and gray areas of the chart. White areas designate metal combinations that are safe to mix.

Other Forms of Corrosion

In addition to uniform and galvanic corrosion, other forms of corrosion can play a role in fastener material selection (and potential mediation efforts in a given application), depending on specific characteristics of the application and/or environment.

Pitting Corrosion

Pitting corrosion (also known as “pitting”) requires that only one metal is present, where an electrolyte in the environment sets up an attack system. Pitting is an extremely localized corrosive process, typically caused by a breach of a protective coating or oxide film due to mechanical damage or chemical degradation.

MITIGATION TIP:

Proper selection of materials and coatings – based upon on specific awareness of atmospheric and environmental conditions – is the most effective strategy for the prevention and/or mitigation of pitting corrosion.

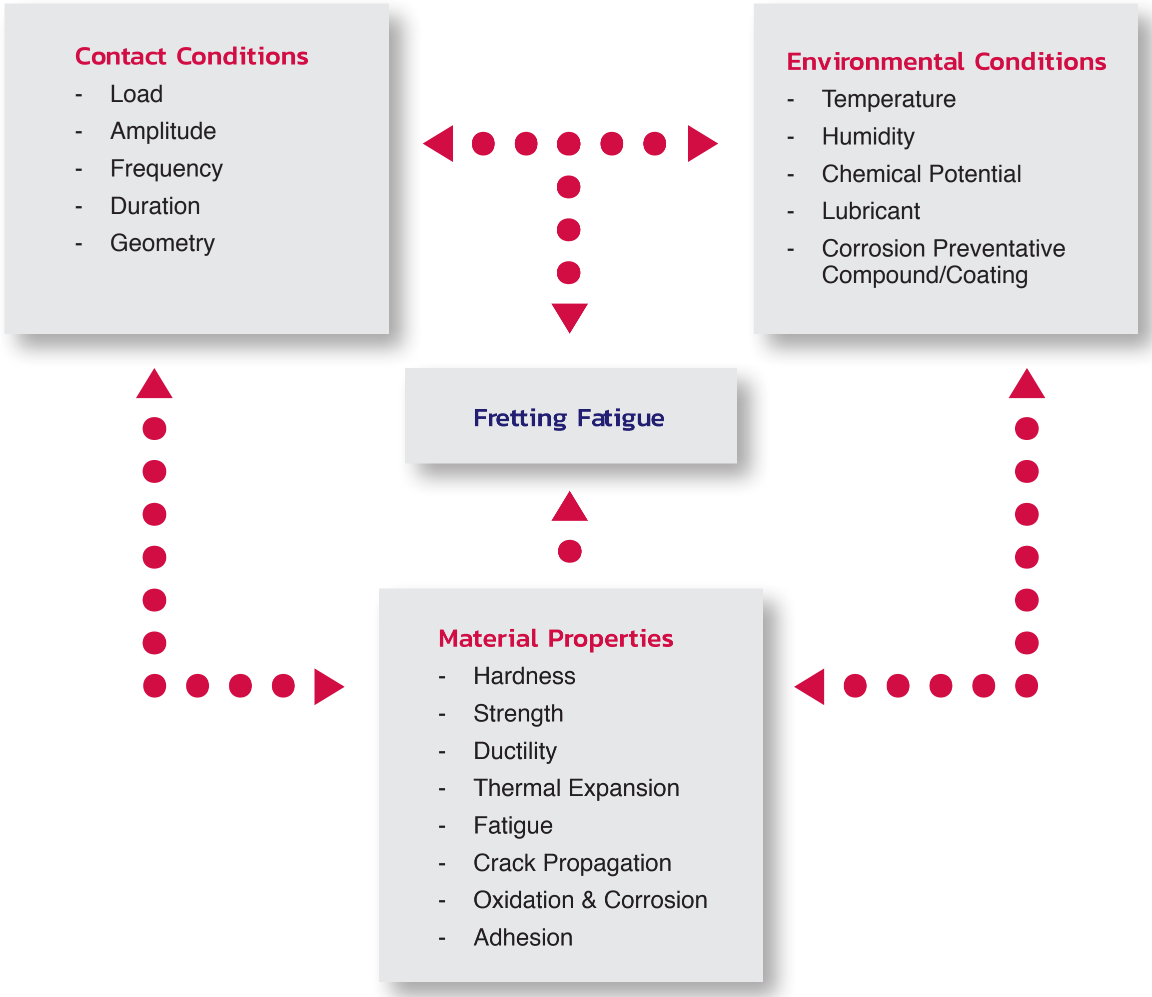
Fretting Fatique

Fretting fatigue (also called “fretting corrosion”) can occur when there is relative motion (often the result of vibration) between two metals that are in contact and under load. Such conditions can cause the surface of one or more of the metals to physically wear away, releasing particles that further accelerate the speed of fretting over time.

MITIGATION TIP:

The use of coatings, lubrication, and adhesives, along with increased clamp load, can all help play a role in reducing fretting fatigue. Most importantly, various material combinations can increase resistance to fretting corrosion, as seen in the accompanying chart.

MECHANICS OF FRETTING FATIGUE



RESISTANCE TO FRETTING FATIGUE

(Material Combinations Under Dry Conditions)

High Resistance	Medium Resistance	Low Resistance
Lead / Steel	Cadmium / Steel	Steel / Steel
Silver Plate / Steel	Zinc / Steel	Nickel / Steel
Silver Plate / Aluminum Plate	Copper Alloys / Steel	Aluminum / Steel
Steel + Conversion Coating / Steel	Zinc / Aluminum	Tin / Steel
	Copper Plate / Aluminum	Aluminum / Aluminum
	Nickel Plate / Aluminum	Zinc-plated Steel / Aluminum
		Iron-plated Steel / Aluminum

Stress Corrosion

Stress corrosion and stress corrosion cracking occur when a metal is subjected to both corrosion and static tensile stress at the same time. Stress corrosion and stress corrosion cracking can be difficult to detect.

MITIGATION TIP:

Several methods can be used to minimize the potential of stress corrosion cracking. Choose a material that is resistant to the specific environmental or chemical factors leading to corrosion. Avoid design features such as corrosion pits that can produce crack initiation sites. Use surface treatments and coatings to increase surface resistance. Reduce exposure of end grains that can act as initiation sites.

Corrosion Fatigue

A similar type of corrosion to stress corrosion, corrosion fatigue involves a cyclic or dynamic stress in combination with corrosion, rather than static tensile stress.

MITIGATION TIP:

The selection of materials that offer increased fracture toughness involves a trade-off with strength. (There is usually an inverse relationship between fracture toughness and strength.)

Erosion Corrosion

Erosion corrosion occurs as the result of the interaction of an electrolyte solution in motion relative to a metal surface. The fluid motion results in wear and abrasion. This type of erosion is commonly found in pipelines, valves, cooling and boiler systems, propellers and impellers, and other components.

MITIGATON TIP:

Generally speaking, the use of harder metals can improve erosion corrosion resistance. Surface smoothness, fluid density and velocity, and angle of impact are other important factors to consider.

Additional Forms of Corrosion

Exfoliation corrosion, microbiological corrosion, liquid and solid metal embrittlement, molten salt corrosion, filiform corrosion, stray-current corrosion, and grooving corrosion (affecting carbon steel) are additional forms of corrosion that can have adverse effects on metal installations.

MITIGATION TIP:

Understanding the dynamics of each type of corrosion can help determine the materials, coatings, and/or other mitigation strategies that are appropriate in each situation.

PROPER METAL SELECTION

In most applications, proper material selection is the key to avoiding problems associated with corrosion, both in fasteners and in structures they are designed to secure. With proper analysis of the environment and application, materials can be selected that help minimize potential problems. Some metals and alloys are more generally resistant to the effects of corrosion than others, while some are more suitable in the face of specific, defined environmental challenges.

A wide range of materials are available for use in the manufacturing of fastener products, allowing project teams to tailor specific fastener solutions to meet the needs of any application.

- Alloy Steels
- Aluminum Steels
- Carbon Steels
- Copper Steels
- Stainless Steels
- Non-Ferrous Steels
- Super Alloys
- Titanium
- Tool Steels
- Others

COATINGS & PLATINGS

Coatings and platings play an important role in the prevention and mitigation of potential fastener corrosion issues in many applications. Generally speaking, coatings and platings are less expensive than employing an upgrade to premium material (e.g., upgrading from basic carbon steel to premium stainless steel). In addition to providing corrosion protection, coatings and platings can help improve appearance, control torque tension, minimize thread seizure, and serve as product identifiers.

There are two main types of coatings. Barrier coatings act as a physical shield, protecting a metal from its surrounding environment. Sacrificial coatings function to form a sacrificial anode, allowing preferential and controlled corrosion.

The quality of the coating application is critical, due to the fact that any defect can lead to severe localized corrosion. A number of different methods are used to apply coatings, including hot-dipping, sherardizing, electrodeposition, electroless plating, cladding, thermal spraying, physical vapor deposition, sputtering, evaporation, ion plating, laser surface alloying, chemical vapor deposition, brushing, rolling, spraying, and immersion bath. Selection of a preferred coating method for a given application is typically based on an overall analysis of the coating type, substrate, surface area, and possible environmental restrictions.

ZINC

The term "galvanization" refers to the application of a zinc coating to the surface of a metal. Zinc is a less expensive alternative to cadmium and is the most frequently used coating in industrial applications.

PHOSPHATE

In addition to being used for corrosion protection, metal phosphate coatings provide a good surface to which other coatings – such as corrosion inhibitors and other coatings – can adhere. Phosphate coatings can be applied by either a spraying or immersion process (immersion is the preferred process since more homogenous coating is produced).

NICKEL

Nickel is useful as a corrosion protection coating, and as an undercoat for other coatings. The use of nickel-phosphorous coatings provides a superior level of corrosion resistance when compared to the use of nickel coatings alone.

CADMIUM

Cadmium is a preferred coating for steel due to the fact that it provides corrosion protection in moist or marine environments. Environmental concerns are a factor when considering the use of cadmium, and it should be avoided in situations that may contaminate the environment. Zinc and tin coatings can provide suitable alternatives.

SERMAGARD®

SermaGard coatings are widely used in chemical and petrochemical processing, and other applications. A ceramic-metallic sprayed base coat, cured at high temperatures and burnished to allow conductivity, is normally combined with a proprietary fluorocarbon topcoat. The result is a protective coating that can be used at high temperatures, is effective in salt atmospheres, and gives superior corrosion resistance and UV protection.

XYLAN®

Xylan is an "extreme performance" fluoropolymer coating designed to prevent corrosion and facilitate makeup torque on fasteners and machined components. These coatings form "plastic alloys" with unique properties to deliver high-level chemical and corrosion resistance in environments containing water, saltwater, acids, bases, solvents, and other liquids. Xylan coatings are waterborne, VOC compliant, resin bonded, and thermally cured, utilizing a single "dry film" lubricant.

Other Types of Coatings

Aluminum, lead, copper, chromium and tin are additional types of metallic coatings that can enhance corrosion resistance. In addition, organic coatings (such as paint, varnish, and lacquer), can be considered for use in any given application.

Specialty Coatings

A wide range of specialty coatings are available to provide additional performance characteristics when needed for given applications, including lubrication, hydrophobic performance, flexural strength, and other properties.

CONCLUSION

Corrosion is a costly problem that can be successfully avoided and/or mitigated through proper evaluation and materials selection. In potentially corrosive environments, the process of fastener design, manufacturing, and selection requires an awareness of environmental factors and forms of corrosion that may be active in the environment. Other application-specific information is also important in addressing potential corrosion issues.

Through the proper selection and application of materials and coatings, engineers, project managers and purchasing personnel can identify fastener solutions that resist the effects of corrosion, while meeting other specified application requirements. In this manner, fasteners can be made to ensure expected performance over the expected service life.

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