WHITE PAPER

CORROSION

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REIMAGINING CONNECTIVITY TOGETHER

CORROSION

HOW CONNECTORS PERFORM IN HARSH CORROSIVE ENVIRONMENTS, AND WHY RELIABILITY MATTERS

This white paper presents technical guidelines that drive connector development for harsh and corrosive environments. It explains the main factors driving corrosion and how to make the best interconnection choices for a long-lasting and reliable solution in corrosive conditions..

JEAN-MARIE BUCHILLY
Project Manager, Fischer Connectors

Jean-Marie Buchilly focuses on innovation and creating products that make a difference in the lives of users. He is working closely with Fischer Connectors' customers to deliver new connector technology to the marketplace.

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INTRODUCTION

The main purpose of this white paper is to discuss the key factors that will help you select the best connectivity options to obtain the most reliable and durable solution according to the level of corrosion in your application environment.

CORROSION, AN EVERYDAY LIFE PROBLEM

Corrosion is a process known to everyone who owns a car. In essence, rust is the corroded product of iron – iron gets corroded and its atoms slowly detach from the raw material when bonding to hydroxide molecules. Iron oxide is the reddish product we call rust. It has been widely used since antiquity as a pigment and is also used nowadays, for example, as a contrast agent in MRI imaging. Corrosion can affect almost any metal under specific environmental conditions. It is a chemical reaction between two materials (or two components of the same alloy) and an electrolyte. Certain materials offer great corrosion resistance, as their limit to trigger the corrosion chemical reaction is much higher than the usual chemical conditions we experience in our everyday lives.

DIFFERENT TYPES OF CORROSION

Corrosion is a process whereby a material degrades to a more stable state, such as an oxide or sulfide. This chemical reaction is generally triggered by external factors (exposure to corrosive agents) and can be dramatically increased by ill-adapted component design. The choice of material and that of its protective coating are critical factors to control when designing parts that will be exposed to the environment.

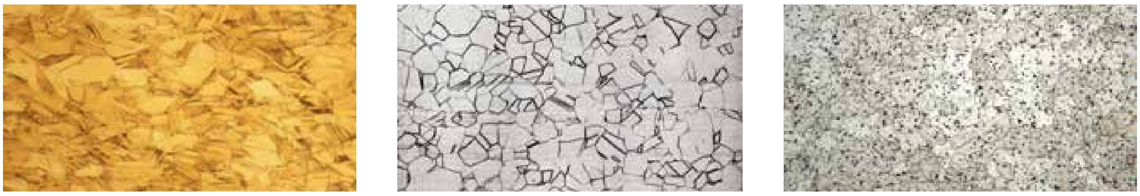
Three elements are needed to start a corrosion reaction:

1. Electrically conductive materials (e.g. brass, stainless steel, aluminum)
2. Components that have different electrolytic potentials
    - The more positive one will be the cathode
    - The more negative one will be the anode
3. An electrolyte medium (e.g. salt water)

A catalyst can speed up the reaction

- Common catalysts are based on oxygen or sulfur chemicals.

Most metals (alloys) have a non-homogenous lattice, which exposes some more reactive compounds to the corrosion process.



ALUMINUM | STAINLESS STEEL 316L | BRASS

FIG.1

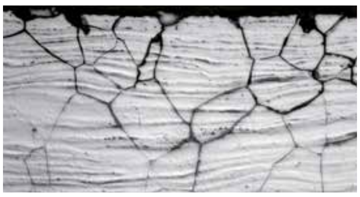
The grain material and the intergrain material can react very differently to chemicals, and associated corrosion can vary strongly. Materials' reactions to corrosion can differ considerably due to these structural differences (Fig. 1).

This inhomogeneous state affects corrosion speed, and specific corrosion mechanisms preferentially affect certain materials. Different effects on corrosion are described and categorized. It is, however, always the same chemical reaction that occurs.

The most common types include :

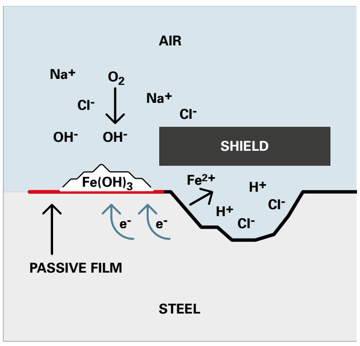
A. Pitting corrosion

This very local corrosion type occurs mainly on passivized alloys. The common alloys subject to pitting corrosion are stainless steel or aluminum, since their granular composition may create local corrosion cells that generate pits.



B. Intergranular corrosion

This corrosion mechanism is generated by the difference in electrolyte potential between the grain and the intergranular phase of the alloy. It is usually the intergranular material of the alloy that dissolves due to the galvanic corrosion effect. The material gets sandy on the surface and slowly degrades.



C. Crevice corrosion

Crevice corrosion occurs mainly on part assemblies and is localized on parts' interfaces. The crevice is created by a zone where, due to capillarity effects, the electrolyte accumulates, generating a mixture of electrolyte and corroded material that acts as a catalyst. The geometry of the crevice prevents the mixture from being removed, thus inducing more and more corrosion which increases the crevice. Crevice corrosion is mainly found on bolts and plate assemblies.

D. Stress corrosion cracking

Stress is not actually a corrosion mechanism in itself but acts as a catalyst in a corrosive environment which under unstressed situations would not corrode the material. Stress can therefore trigger a local corrosion effect.

E. Hydrogen embrittlement

Hydrogen is a gas that can affect the structural integrity of various materials. The mechanism is not exactly a corrosion effect, but rather an induced mechanical or chemical stress in the material lattice. Since hydrogen atoms are extremely small, they easily diffuse into the material lattice as temperature rises (thermal excitation increases gaps among atoms) and combine with material, thus creating internal stress "pockets" that can slowly shear or crack the material.

CHEMICAL REACTION DETAILS

Corrosion is a galvanically induced effect.

The galvanic corrosion process consists in an oxide reduction chemical reaction that is triggered by the electrolytic potentials of each material present in the reaction.

FIG.2

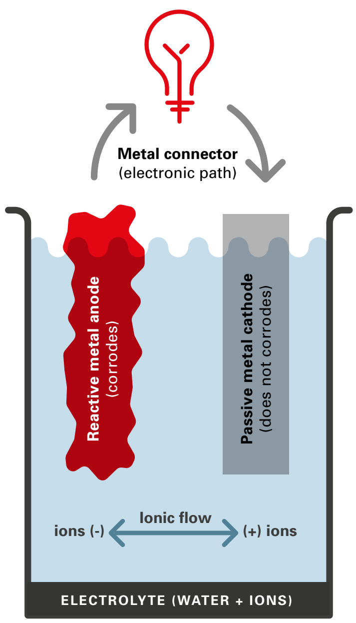
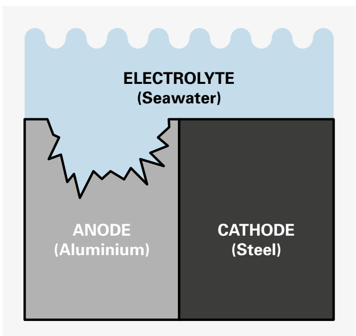


FIG.3



In order to properly design components for use in a corrosive environment, material choice is critical. Choosing a mix of materials that have very similar electrolytic potentials is the key to success. The typical bad example is aluminum coated with chromium. The chromium offers great resistance, but once the coating gets damaged – thus exposing the raw aluminum – a corrosion potential is induced.

The corrosion potential can easily be seen in an electrolytic potential table (Fig 5).

Environmental parameters, such as strain temperature or microbial pollution, can make these parameters vary and therefore induce corrosion in commonly passivized materials.

In the following example, the electrical potential triggering the corrosion is induced by the difference in galvanic corrosion potentials and the presence of electrolyte that allows the current to flow from one exposed surface to the other.

Aluminum has a lower potential than steel and gets corroded as it takes the place of the anode in this reaction (Fig. 3). If we replaced the steel with magnesium, for example, the aluminum would no longer be corroded, as the anode would be transferred to the magnesium.

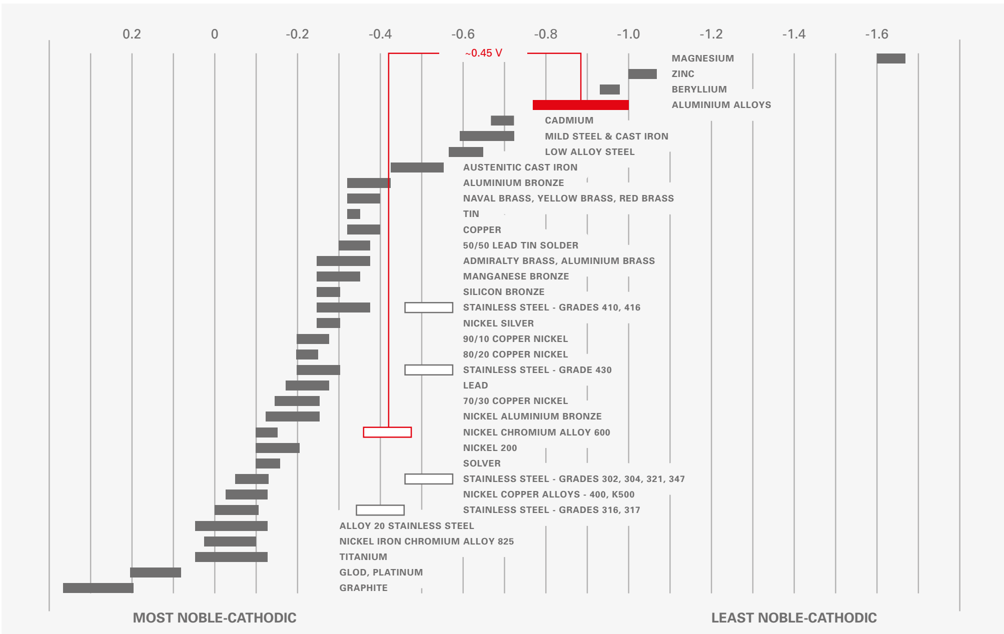
Corrosion speed is also linked to the galvanic potential intensity difference between the two alloys and the ratio between the

FIG.4

exposed surfaces. If the anode has a small exposed surface compared to the cathode, pitting corrosion will grow rapidly and slow down as the pit surface increases, thus reducing the current flow and thereby lowering the corrosion rate.

This chemical process is commonly found on boat hulls where a sacrificial anode is used (Fig. 4) – usually made of magnesium alloy, since this has one of the lowest anodic potentials in the metallic alloys class. In this example, the sacrificial anode corrodes leaving the steel hull intact – at least until the sacrificial anode has been fully corroded.

FIG.5



PROTECTION AGAINST CORROSION

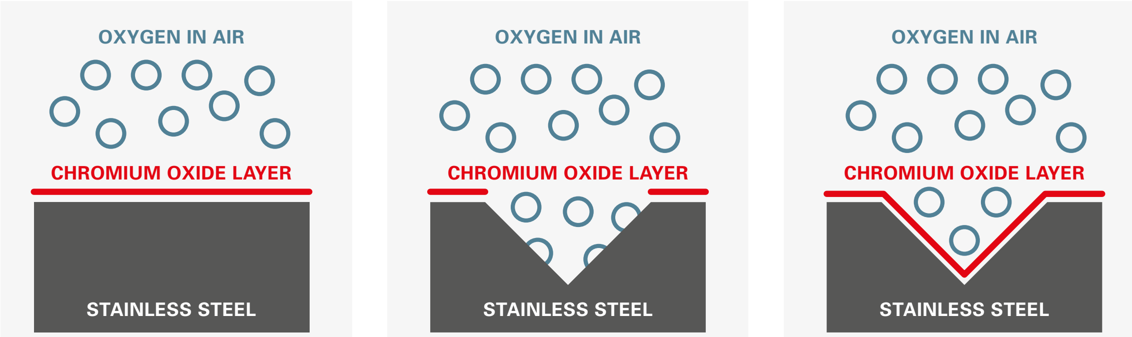
These corrosion mechanisms can occur in many different situations, as materials are rarely homogeneous. Used in mechanical assemblies, they come into contact with other metals that have different potentials.

There are many mechanisms that protect parts and assemblies from corrosion; one of the most common is to coat the surfaces with a nobler material that is much less likely to get corroded. This allows the use of mechanically optimized materials while obtaining the best corrosion resistance from the coating.

The most common coating on metallic parts is nickel chromium or thin gold-based layers applied with a galvanic or sputtering deposition process.

Another solution is to add a protective phase directly into the alloy composition. This mechanism is commonly used in stainless steel. The chromium phase (16-18% of total mass) added to the steel reacts with oxygen (in the air for example) to create a sealed layer of chromium oxide on the surface that protects the raw material from being exposed to the electrolyte, thus preventing corrosion (Fig. 6).

FIG.6



1. Chromium oxide layer protecting stainless steel
2. Chromium oxide layer damaged by machining
3. Chromium oxide layer re-formed automatically

The main drawback with coating is that once the matrix material gets exposed, due to mechanical wear or pin holes for example, corrosion speed can increase dramatically, since it is linked to the galvanic potential intensity difference between the two alloys as well as to the ratio between the exposed surfaces.

The material potential differences define the voltage, and the exposed surface ratio affects the current intensity. Therefore, if the anode has a small exposed surface compared to the cathode, corrosion will grow rapidly and eventually slow down once the surface ratio has equilibrated enough to reduce the current flow.

COMMON MATERIALS AND COATING USED IN CIRCULAR CONNECTORS

A. Brass

- With nickel coating
- With chromium coating

Brass is the most corrosion-resistant material with a galvanic potential close to the coating. This ensures that, even when exposed, the current density and voltage available for corrosion is insufficient to start a corrosion reaction (in most conditions).

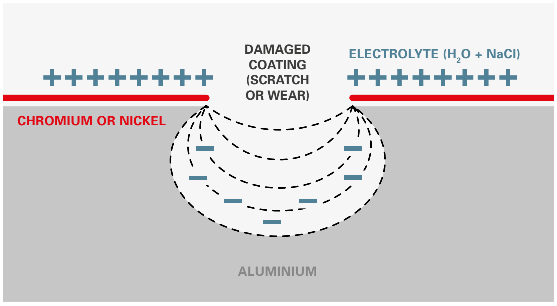
Nickel provides good protection but it slowly becomes corroded, and coated parts have a limited lifespan if coated only with nickel. Chromium is much more resistant to most common corrosive agents.

B. Aluminum

- With nickel coating
- With chromium coating
- Anodized (aluminum oxide Al2O3)

Aluminum is resistant in its anodized state, but this coating is highly problematic if a cleaning process is required, since the porosity of the Al2O3 structure captures microorganisms or active ions.

FIG.6



Aluminum is also often coated with chromium or nickel. This produces parts that offer great corrosion resistance as long as the coating stays sealed. Once the coating has been damaged through wear or scratching, the corrosion process can start in the exposed aluminum area. This failure mode is particularly dramatic as two factors contribute to the corrosion process (Fig. 7):

1. A high galvanic potential difference between aluminum and chromium or nickel
2. The exposed surface area ratio (between the scratch and the surface of the part)
   a. The surface ratio between the exposed zone and the coating is generally high
   b. This causes a high positive charge density that speeds up the reaction until the anode exposed surface area has sufficiently grown to equilibrate, thus slowing down the reaction.

As scratches are generally very small compared to the total surface area of the part, the effect is dramatically fast on these kinds of coating.

Anodizing is not a coating in itself but the artificial growth of an oxidation layer (passivation) of the aluminum surface (Al2O3).

c. Stainless steel

Stainless steel is one of the best materials for corrosion resistance, since corrosion protection is embedded within the material itself. The passivation induced by the chromium phase in the alloy allows for every scratch or wear to re-coat automatically, thus preventing corrosion from appearing (Fig. 6).

There are several grades of stainless steel with various compositions, making it optimized for parts machining (AISI 304) or welding, for example. The grade Fischer Connectors uses as standard is AISI 316L, which is the best in class in terms of corrosion resistance in many applications.

Stainless steel offers great chemical resistance and an outstanding level of passivation layer protection against standard environmental corrosion. This makes it very difficult for active ions or microbiological entities to diffuse into the material lattice, ensuring that equipment is very easy to clean and sterilize.

CONNECTOR SOLUTION RECOMMENDATION

Fischer Connectors offers a full range of materials and coatings that fulfill most demanding applications. The following pages are intended to help you select the correct range according to your environmental conditions:

A. Salt and marine environment

Seawater and salt mist can act as an electrolyte, since the salt phase dissolved in the water strongly increases its conductivity, enabling galvanic corrosion effects to occur. The goal is to choose materials and coatings that create the least galvanic current. The coating in itself is insufficient, as it can be damaged and induce dramatic galvanic corrosion effects.

PRODUCT LINE	RAW MATERIAL	COATING
RECOMMENDED PRODUCT LINES		
BRASS	Brass	Ni + Cr
STAINLESS STEEL	Stainless steel 316L	Uncoated
ULTIMATE	Brass[1)]	Ni
FIBEROPTIC	Brass	Ni + Cr
MINIMAX	Brass	Ni + Cr
MEDIUM PERFORMANCES		
ALULITE	Aluminum	Ni + Cr [2)]
ULTIMATE	Aluminum[1)]	Ni
NOT RECOMMENDED		
ALULITE	Aluminum	Anodized [2)]

1) Available in Brass or Aluminum
2) Available in anodized or chromium plated

B. Medical, food and pharmaceutical applications

In medical, food or pharmaceutical applications, the main process where corrosion occurs is sterilization or cleaning (mostly chemical processes). Two parameters need to be taken into consideration: the material's compatibility with sterilization products for both coating and raw material, and the diffusion factor occurring on the surface of the part.

If the component has a porous surface, pathogenic agents can diffuse inside the material lattice, making it impossible to sterilize it completely. Anodized aluminum is a typical worst-case scenario for sterilization.

PRODUCT LINE	RAW MATERIAL	COATING
RECOMMENDED PRODUCT LINES		
STAINLESS STEEL	Stainless steel 316L	Uncoated
BRASS	Brass	Ni + Cr
PLASTIC	PEI Thermoplastic	Uncoated
MEDIUM PERFORMANCES		
ULTIMATE	Brass [1)]	Ni
ULTIMATE	Aluminum [1)]	Ni
FIBEROPTIC	Brass	Ni + Cr
MINIMAX	Brass	Ni + Cr
ALULITE	Aluminum	Ni + Cr [2)]
NOT RECOMMENDED		
ALULITE	Aluminum	Anodized [2)]

1) Available in Brass or Aluminum
2) Available in anodized or chromium plated

C. Oil and gas applications

In oil and gas applications, we can distinguish two types of environmental exposure: salt and seawater in offshore exploration see salt and marine environment and corrosion induced by corrosive extraction products (hydrocarbons).

The corrosive effect of these products is generally due to the level of sulfide and chloride products. The best material for sulfide resistance is premium stainless steel (316L). Stress corrosion is generally the most discussed topic in the market, as it affects pipelines and drilling tools subject to extreme levels of mechanical stress. Connectors, on the other hand, are less exposed to stress corrosion but remain exposed to cleaning chemicals and high temperature variations.

PRODUCT LINE	RAW MATERIAL	COATING
RECOMMENDED PRODUCT LINES		
STAINLESS STEEL	Stainless steel 316L	Uncoated
BRASS	Brass	Ni + Cr
ULTIMATE	Brass[1)]	Ni
FIBEROPTIC	Brass	Ni + Cr
MINIMAX	Brass	Ni + Cr
MEDIUM PERFORMANCES		
ALULITE	Aluminum	Ni + Cr[2)]
PLASTIC	PEI Thermoplastic	Uncoated
ULTIMATE	Aluminum[1)]	Ni
NOT RECOMMENDED		
ALULITE	Aluminum	Anodized[2)]

1) Available in Brass or Aluminum
2) Available in anodized or chromium plated

ABOUT FISCHER CONNECTORS

Fischer Connectors has been designing, manufacturing and distributing high-performance connectors and cable assembly solutions for more than 60 years. Known for their reliability, precision and resistance to demanding and harsh environments.

Fischer Connectors' products are commonly used in fields requiring faultless quality, such as medical equipment, industrial instrumentation, measuring and testing devices, broadcast, telecommunication and military forces worldwide.

Primary design and manufacturing facilities are located in Saint-Prex, Switzerland, with subsidiaries and distributors located worldwide.

fischer® CONNECTORS

HEADQUARTERS
Chemin du Glapin 20
CH-1162 Saint-Prex
fischerconnectors.com

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