

GUIDE TO SELECTING ENGINEERED MATERIALS FOR CORROSION RESI

METALS

Corrosion is often envisioned as rusting or tarnishing. However, corrosion may occur in other forms — cracking or loss of strength or ductility, for example. In general, most types of corrosion occur by an electrochemical mechanism. But corrosion products need not be visible, and weight loss of the parent metal need not be appreciable.

Forms of corrosion damage

There are five basic forms of corrosion. Each form is classified by external appearance or altered physical properties.

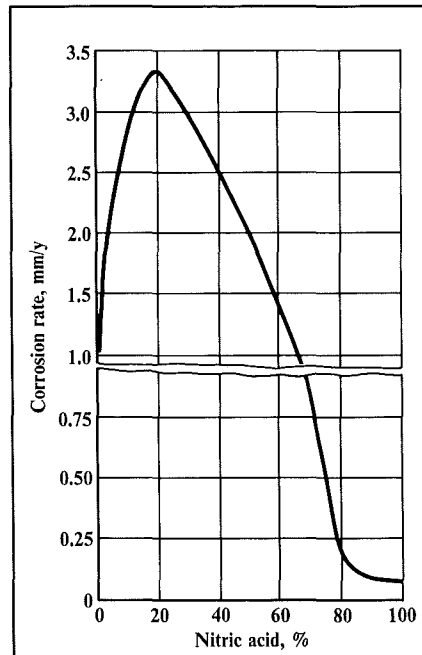
Uniform attack

This form includes rusting of iron, tarnishing of silver, "fogging" of nickel, and high temperature oxidation of metals. Uniform corrosion is measured metal penetration or weight loss of metal (excluding any adherent or non-adherent corrosion products) per unit time.

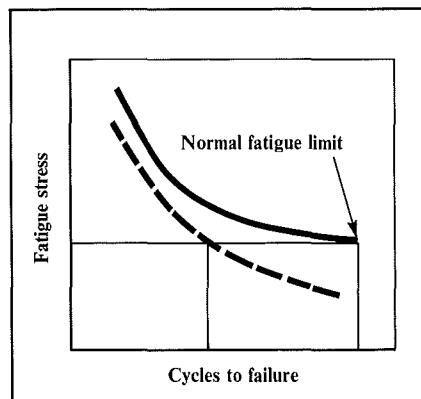
Common units for measuring rate of uniform corrosion include mm/yr, g/m²/day, or in./yr. Plain carbon steel, for example, corrodes in seawater at a relatively uniform rate of about 0.13 mm/yr (0.005 in./yr). These figures represent time-averaged values. Depth of penetration is not proportional to time. Corrosion occurs more rapidly initially than corrosion after prolonged exposure. Hence, duration of exposure should always be given when corrosion rates are reported.

Pitting

A localized type of attack, pitting corrosion progresses more rapidly



The corrosion rate of commercially pure aluminum depends on the concentration of nitric acid.



Normal fatigue behavior of a metal: the lower the applied stress, the longer the fatigue life, top. Fatigue stress of the same material can be depressed by the presence of a corrosive environment: the same applied stress results in a much shorter fatigue life, bottom.

on some areas of a metal's surface than others. Pitting is considered deep if appreciable attack is confined to relatively small areas on the metal. The pitting factor is sometimes used as an expression for the ratio of deepest metal penetration to average metal penetration.

Shallow pitting may occur in iron buried in soil, while certain stainless steels submerged in seawater succumb to deep pitting. In addition, a special type of pitting corrosion — impingement attack (corrosion-erosion) — occurs with many metals subjected to liquids flowing at high velocities. Copper and brass condenser tubes are subject to this type of attack.

There are two other common forms of specialized pitting corrosion. Fretting corrosion is caused by slight relative motion (often vibration) between two contacting surfaces. A series of small pits appears at the interface of the contacting surfaces.

Cavitation-erosion results from the forming and collapsing of vapor bubbles at a dynamic metal-liquid interface (as on the trailing faces of pump impeller vanes). The resultant pitting often looks like a honeycomb of small, deep fissures.

Parting

This type of corrosion occurs when one or more reactive components of the alloy corrodes preferentially. Left behind is a porous residue that may retain the original shape of the alloy. Parting usually occurs with noble metals such as gold-copper and gold-silver, and can be used for refining gold. For example, alloys of gold and silver may react with concentrated nitric acid to form silver

Selecting materials for corrosion resistance

STANCE

nitrate and a porous residue or powder of pure gold.

Dezincification is a specific type of parting corrosion that attacks alloys containing zinc (notably yellow brass) in which the zinc corrodes preferentially. The alloy may appear undamaged except for surface tarnish, but its tensile strength and ductility will be drastically reduced.

A common example of dezincification can be found with brass pipe. Dezincified brass pipe often retains enough strength to withstand water pressure until it is subjected to additional stress from water hammer or an attempt at uncoupling the pipe. The weakened pipe then cracks or tears open easily. Copper base alloys containing aluminum also may suffer corrosion attack that resembles zincification. In this case the aluminum corrodes preferentially.

Intergranular corrosion

This form of corrosion locally attacks grain boundaries of a metal; resulting in loss of strength and ductility. With the relatively large grain areas acting as a cathode, material in grain boundaries acts as the anode, and therefore corrodes. The attack is often rapid, penetrating deeply into the metal and possibly causing catastrophic failure.

Improperly heat treated 18-8 stainless steels and some copper-aluminum alloys are subject to

Galvanic series of metals in seawater. Note how some metals occupy two positions, depending on whether they are active or passive. Active metals achieve equilibrium with their ions. Passive metals cannot achieve equilibrium due to formation of a surface film.

Selecting materials for corrosion resistance

intergranular corrosion. Nickel heated in a sulfur-bearing atmosphere may also fail due to sulfur penetrating along grain boundaries.

Cracking

If a metal cracks when subjected to repeated or intermittent tensile stress, it is said to fail by corrosion fatigue. The corrosive environ-

Most susceptible to corrosive attack

Magnesium
Magnesium alloys
Zinc
Aluminum 5052H
Aluminum 3004
Aluminum 3003
Aluminum 1100
Aluminum 6053T
Alclad
Cadmium
Aluminum 2017T
Aluminum 2024T
Mild steel
Wrought iron
Cast iron
Ni-Resist
13% Chromium stainless steel, type 410 (active)
50-50 lead-tin solder
18-8 stainless steel, type 304 (active)
18-8, 3% Mo stainless steel, type 316 (active)
Lead

Least susceptible to corrosive attack

Tin
Muntz metal
Manganese bronze
Naval brass
Nickel (active)
76% Ni-16% Cr-7% Fe (Inconel 600) (active)
Yellow brass
Aluminum bronze
Red brass
Copper
Silicon bronze
5% Zn-20% Ni, Bal. Cu (Ambrac)
70% Cu-30% Ni
88% Cu-2% Zn-10% Sn (composition G-bronze)
88% Cu-3% Zn-6.5% Sn-1.5% Pb (comp. M-bronze)
Nickel (passive)
76% Ni-16% Cr-7% Fe (Inconel 600) (passive)
70% Ni-30% Cu (Monel)
Titanium
18-8 stainless steel, type 304 (passive)
18-8, 3% Mo stainless steel, type 316

ment plays an important role because without it, the metal would achieve its normal fatigue life despite the induced stress.

Stress corrosion cracking occurs when a metal cracks immediately or after a given time while subjected to a constant tensile stress and exposed simultaneously to a corrosive environment. The cracks may be granular or transgranular, depending on the metal and environment.

Almost all structural metals are subject to stress corrosion crack-

ing in some environments. Fortunately, required stress levels are high.

Corrosion susceptibility

Because so many different metals may fulfill strength, weight, fatigue life, and other application requirements, corrosion resistance to a particular environment often determines final selection of a specific metal or alloy.

Occasionally, no metal may offer an economical combination of

mechanical performance and corrosion resistance. For these instances a low-cost base metal (often a carbon steel) may be specified with a corrosion resistant surface contacting the corrosive agent. The protective surface may be in the form of sacrificial coatings, passivation and corrosion inhibitors, barrier coatings, or cathodic protection.

Despite the versatility of coatings, metals offering suitable performance and corrosion resistance are usually the preferred choice for new applications. And all metals have some degree of corrosion resistance for some applications.

For example, carbon and low alloy steels, while normally not chosen for their corrosion resistance, do resist corrosion from concentrated (above 90%) sulfuric acid. These steels should not be used, however, with hydrochloric, phosphoric, or nitric acids.

Stainless steels

Stainless steels were developed as corrosion resistant substitutes for carbon and low alloy steels. The more than 70 available types of stainless steels can be divided into four basic groups: austenitic, martensitic, ferritic, and duplex. Each offers varying degrees of mechanical performance and corrosion resistance.

INFORMATION TO HELP YOU MAKE BETTER MATERIAL SELECTIONS

NGK would like to help you increase your knowledge of high quality beryllium copper alloys. These alloys offer a combination of properties not found in other materials.

A new 24-page brochure outlines the major characteristics of beryllium copper and provides important data on the importance of proper heat treating to develop the most desirable properties of beryllium copper alloys.

In addition, the new brochure provides data on designing with beryllium copper with details on spring characteristics, stress relaxation, electrical conductivity and heat generation, fatigue and corrosion resistance. It also has a section on the proper use of beryllium copper in the manufacturing process with information on formability, heat treatment, surface cleaning, preparation and plating and joining techniques.

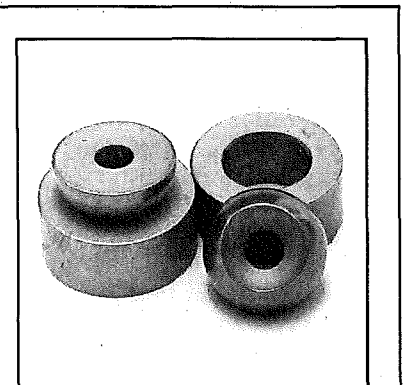


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APPLICATION

Nitrided Cb-30Ti-20W is particularly effective in environments involving simultaneous corrosion and wear. Fansteel's Tribacor 532N was selected for these half-ball/seat combinations for use in oil wells.

Nickel and high-nickel alloys

Nickel has outstanding resistance to hot or cold alkalis, being second only to possibly silver or zirconium. Nickel resists stress corrosion cracking in typical chloride environments, but may be susceptible in caustic environments if highly stressed. Corrosion tests should be long in duration to obtain an accurate corrosion rate because a nickel oxide film forms that protects the surface from further corrosion.

Because nickel does not readily discharge hydrogen from non-oxidizing acids, it can be used with dilute sulfuric, hydrochloric, and phosphoric acids. It also can be used in the presence of anhydrous ammonia and ammonium hydroxide solutions of less than 1% concentrations.

Nickel-copper

Alloying nickel with 30 to 33% copper produces an alloy with properties similar to that of pure nickel, but with some improvements. These improvements allow handling sea and brackish waters, and excellent performance at high

fluid velocities.

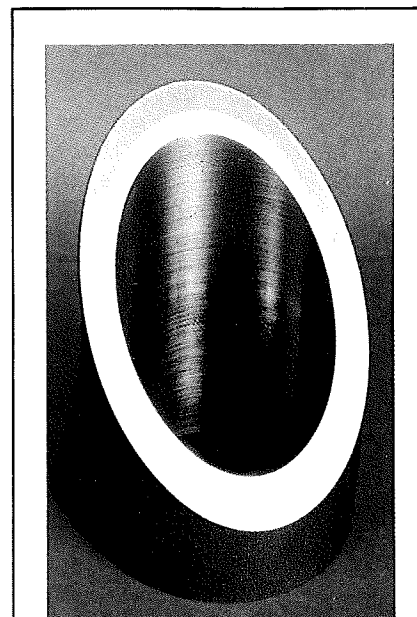
This alloy's corrosion resistance in nonoxidizing acids is improved over that of pure nickel. It also has excellent resistance to hydrofluoric acid, but it is not resistant to oxidizing media such as nitric acid, ferric chloride, chromic acid, wet chlorine, sulfur dioxide, or ammonia.

Nickel-molybdenum

This alloy contains about 70% nickel, with low carbon and silicon and no chromium. Its chief alloying element, molybdenum, provides significant corrosion resistance to reducing environments, especially hydrochloric acid.

Nickel-chromium-iron

These nickel base alloys resist corrosive atmospheres at elevated temperatures. Depending on the specific alloy, they can be readily fabricated and welded; be used in air at temperatures to 1,100°C (2,000°F), provide good corrosion resistance against sulfuric acid; provide high-temperature strength; and resist aqueous



APPLICATION

Highly corrosion-resistant 50%Ni/50%Cr alloy powder has been laser fused to the surface of this SUS 321H stainless-steel tube by Nippon Kokan for high-temperature corrosion resistance. The tubes are used in chemical-processing boilers.

Allegheny Ludlum Has Light Gauge Stainless Steel Down

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Allegheny Ludlum is shaping new industry standards for flatness and uniformity in light gauge specialty steel strip. A new, highly effective tension-leveling line has been added to our production facility in Wallingford, Connecticut. Our ability to provide stainless and specialty steel strip has been greatly enhanced because flat strip is our new strength.

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flat steel strip is our specialty. In fact, we believe that our flatness capability is without equal. We are literally knocking the competition flat.

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Name _____
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corrosion.

Other nickel base alloys

Adding a variety of other elements produces alloys that are especially well-suited to specific applications. Examples include alloys that can be used in the as-welded condition and those that provide high strength and resistance to a variety of chemicals at high temperatures.

Copper and its alloys

Copper is considered a noble metal, which means in part that it is highly corrosion resistant. It is especially compatible with most industrial, marine, and urban atmospheres and water and seawater. Its high thermal and electrical conductivity add to its versatility. It lacks strength, however, and is often alloyed with zinc, aluminum, tin, or nickel to improve mechanical properties.

Copper-zinc

If zinc is alloyed with copper in concentrations near or greater than 15%, dezincification may occur in some environments. Slight additions (about 1%) of tin can alleviate this problem somewhat. High-zinc alloys, however, resist sulfide better than do low-zinc brasses.

Copper-tin

These alloys (bronzes) contain phosphorus to impart oxidation resistance to the copper-tin base. They are among the oldest alloys known, and the recovery of bronze artifacts that have survived hundreds of years of exposure to a variety of atmospheres, waters, and soils attests to bronze's corrosion resistance.

Copper-aluminum

Corrosion performance (particularly dealloying resistance) of these alloys is highly dependent on their microstructure. All-alpha, single phase alloys rarely experience dealloying, except when high temperature, acidic environments are encountered. These single phase microstructures generally occur when aluminum content is held below 8%. Heat treating can improve dealloying resistance of these alloys, which are often called aluminum bronzes. Small amounts

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of tin can be added to inhibit intergranular stress corrosion. Aluminum bronzes generally are resistant to corrosion from chloride potash solutions, non-oxidizing mineral acids, and many organic acids.

Copper-nickel

Cupronickels are most widely used in saltwater service, and have excellent resistance to biofouling and stress corrosion cracking. They boast the highest resistance to stress corrosion cracking in ammonia and ammoniacal environments of any copper alloy.

Aluminum alloys

All non-heat-treatable alloys feature high resistance to general corrosion. Therefore, their selection is usually based on other considerations. Alloying with magnesium imparts the highest resistance to corrosion from alkaline solutions of any aluminum alloy, while retaining good general corrosion resistance.

Aluminum alloys in the 2000 series and those in the 7000 series that contain copper feature a lower resistance to general corrosion than do other aluminum alloys. Copper is alloyed into the aluminum for applications where corrosion resistance is secondary to strength.

Titanium

Corrosion resistance is provided by a stable, protective, strongly adherent surface oxide film. Additions of alloying elements affect corrosion resistance because they can alter the composition of this oxide film.

The oxide film is attacked by only a few substances — most notably hydrofluoric acid. Titanium also resists attack by moist chlorine gas, but if moisture concentration in the gas falls below 0.5%, rapid or even catastrophic failure can result. Titanium is immune to all forms of corrosive attack in seawater and chloride salt solutions at ambient temperatures.

Titanium also boasts a very high resistance to erosion corrosion. In experiments with sand-laden, rapidly moving seawater, titanium proved to be 20 times more resistant to erosion than the best

copper base alloys.

Tantalum

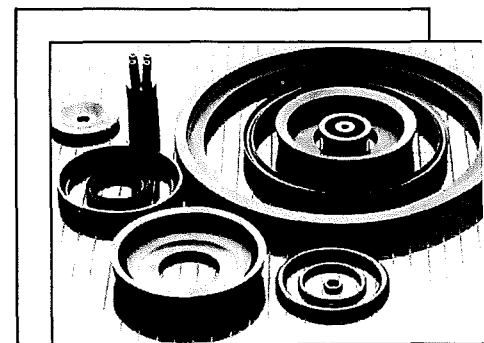
Tantalum is inert to practically all organic and inorganic compounds at temperatures under 150°C (300°F). Exceptions are hydrofluoric acid and fuming sulfuric acids. At temperatures under 150°C it is inert to all concentrations of hydrochloric and nitric acids, 98% sulfuric acid, 85% phosphoric acid, and a long list of common fluids.

Conversely, any acid medium containing fluoride ion, except chromium plating baths, will rapidly attack tantalum. Hot oxalic acid is the only organic acid known to attack tantalum.

Zirconium

Zirconium is resistant to mineral acids, molten alkalis, alkaline solutions, and most organic and salt solutions. It has excellent oxidation resistance in air, steam, CO₂, SO₂, N₂, and O₂ at temperatures to 400°C (750°F). Zirconium's excellent corrosion resistance depends on the integrity of an inert, passive oxide film that forms on exposure to air.

Zirconium is attacked by corrosion in hydrofluoric acid, wet chlorine, concentrated sulfuric acid, aqua regia, ferric chloride, and cupric chloride solutions. ■



APPLICATION

O-rings and seals made of perfluoroelastomer are chemically inert up to 600°C. DuPont's Kalrez resists attack by nearly all chemical reagents, including ethers, solvents, ketones, esters, amines, oxidizers, fuels, acids, and alkalis.

Selecting materials for corrosion resistance