Corrosion Resistance Tables

Metals, Nonmetals, Coatings, Mortars, Plastics, Elastomers and Linings, and Fabrics

Fourth Edition, Revised and Expanded

Part C, P-Z

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ADDITIONAL VOLUMES IN PREPARATION

Preface

The field of corrosion resistance is one of constant change. Research and development is constantly underway, involving both new materials and expanding the uses of known materials. These advances are particularly important for such areas as chemical processing and pollution control. Increased knowledge of corrosion resistance and the mechanisms of corrosion is a vital factor in this work.

This fourth edition of the corrosion resistance tables has been prepared in an attempt to provide the most current information available. Data on the corrosion resistance for the materials and corrodents covered in the previous editions have been greatly expanded, and data for 96 additional corrodents have been incorporated in this edition.

Philip A. Schweitzer, P.E.

Introduction

For years the chemical engineer has been faced with the problem of selecting the proper material to be used for the construction of processing vessels, storage tanks, valves, piping systems, and whatever else comes into contact with potentially corrosive chemicals. During the early days of the chemical engineering profession, the list of materials from which to choose was relatively small, consisting primarily of various metals and their alloys.

As technology made advances, new alloys were developed as well as synthetic materials such as plastics. Simultaneously, new chemicals came into being, many of which required the newly developed materials of construction for safe handling.

However, the problem of material selection is not limited to the chemical engineer. Many industries that use chemicals in their everyday operations cannot be classified as members of the chemical processing industry, yet they have the same problems of selecting the proper materials of construction to handle these products. This is particularly true in the area of pollution control. Many processes for the elimination of air and/or water pollution involve chemical changes in the pollutants that result in problems of corrosion that were not present before.

The dictionary defines corrosion as "the eating or wearing away by slow degrees," a definition that is rather broad and does not restrict the application of the word to the destruction of metals. This is as it should be because of the availability of so many nonmetallic materials of construction.

Most reference sources for the selection of proper materials of construction are devoted to either a specific group of metals or alloys, plastics, rubbers (synthetic and natural), gasketing materials, or packing materials. An individual with the problem of selecting materials of construction usually must make a selection in more than one of the preceding categories, which necessitates going to several sources for the information. It is the purpose of this book to provide one source from which all the components of a system may be selected, including processing vessels, tanks, pumps, piping, valves, gaskets, packing, etc.

These corrosion tables have been prepared with the intention of assisting not only the practicing engineer, but whoever may be charged with the responsibility of selecting the proper materials of construction for a specific application. Any table of this type should be used only as a guide since it is extremely difficult, and at times impossible, to duplicate actual operating conditions. To fully guarantee the suitability of a particular material of construction, corrosion tests should be conducted under actual operating conditions.

In the tables, all the chemicals are assumed to be in the pure state or in concentrated or saturated aqueous solutions, unless otherwise indicated. Concentration percentages used are by weight.

Two types of notation have been employed to indicate the suitability of a specific material of construction—one for metallic materials and one for nonmetallic materials. This is necessary because their mechanisms of corrosion differ.

CORROSION OF METALLICS

The four most common forms of corrosion of metals are

1. General corrosion
2. Galvanic corrosion
3. Stress corrosion cracking
4. Intergranular corrosion

General Corrosion

Metals resist corrosion by the formation of a passive film on the surface, which in a sense is also corrosion but once formed prevents further degradation of the base metal. Most metals form this film after a period of time of exposure to the air. *Passivation* is the name applied to the chemical treatment procedure that helps to form the film more rapidly. For example, exposure of austenitic stainless steels to nitric acid will produce this protective film.

As long as these films remain intact, they protect the base metal from further attack. Certain chemicals attack various films at varying rates. When this occurs, the metal is said to corrode. Such interaction between a chemical and a metal can be determined from the corrosion tables. This type of corrosion is known as general corrosion.

Galvanic Corrosion

Galvanic corrosion occurs when two or more dissimilar metals are in contact, or when metals having the same analysis have different surface conditions and an electrolyte is present.

Under these conditions an electrolytic cell is formed. All metals and alloys have certain "built-in" properties that cause them to react as an anode or a cathode when in contact with dissimilar metals or alloys. Whether a particular material will react as a cathode or an anode can be determined from the relative positions of the materials in the galvanic series. The farther apart two materials are from each other in the galvanic series, with all other factors being equal, the greater the rate of corrosion. The material closest to the anodic end will be the one to corrode. For example, if tin and zinc were in contact, the zinc would corrode, whereas if tin and copper were in contact, the tin would corrode.

The rate of attack is also affected by the relative size of the materials and the specific electrolyte present. A small anode area in contact with a large cathode area will result in a rapid severe attack. Conversely, a large anode area in contact with a small cathode area will lessen the rate of galvanic attack since the same total electromagnetic driving force of corrosion will be spread out over a larger area. The higher the degree of ionization of the electrolyte, the greater the rate of attack.

Galvanic corrosion can be prevented by judicious use of dissimilar metals.

Galvanic Series

Anodic (corroded) end
Magnesium
Magnesium alloys
Zinc
Aluminum 5052
Aluminum 6061
Cadmium
Aluminum AA 2017
Iron and carbon steel
Copper steel
4–6% Chromium steel
Ferritic stainless (active) 400 series
Austenitic stainless (active) 18-8 series
Lead-tin solder
Lead
Tin
Nickel (active)
Inconel (active)
Hastelloy C (active)
Brasses
Copper
Bronzes
Cupro-nickel alloys
Monel
Silver solder
Nickel (passive)
Inconel (passive)
Ferritic stainless (passive)
Austenitic stainless (passive)
Titanium
Hastelloy C (passive)
Silver
Graphite
Gold
Platinum
Cathodic (protected) end

Stress Corrosion Cracking

All metals are subject to stress corrosion cracking, which results from residual or applied stress in the metal. Residual stresses can occur as a result of cold forming or quenching after heat treating. Annealing after fabrication will minimize these stresses. Applied stresses can result from faulty design, vibrations, flexing, and excessive expansion and contraction due to thermal changes.

The particular corrodent will determine the degree of effect. Halogen salts are among the materials that will attack metals most vigorously when stresses are present.

Intergranular Corrosion

Corrosive attack involving intergranular corrosion occurs only at the grain boundaries of austenitic stainless steels. All austenitic stainless steels contain carbon in small amounts.

When this material is heated to the sensitizing range (850 to 1650°F), such as in welding, carbon is precipitated out at the grain boundaries in the form of chromium carbide. The chromium has been taken from the grain boundaries, changing the composition and making this area even more susceptible to corrosive attack.

This effect can be minimized by annealing the stainless steel after it has been sensitized. This is done by heating the alloy to 1800°F or higher, depending on the specific alloy, and then quickly cooling it through the sensitizing range to prevent the carbon from precipitating out. Another way to reduce this effect is to limit the carbon content to less than 0.03%. This extra-low-carbon (ELC) stainless steel can be welded without the danger of carbide precipitation.

CORROSION OF NONMETALLICS

Plastic materials are attacked by solvation and chemical reactions. Solvation is the penetration of the plastic by corrosive elements that cause softening, swelling, and ultimate failure. Plastics, in contrast to metals, do not exhibit a useful corrosion rate; they usually either completely resist attack or deteriorate rapidly. Because of this difference in corrosion mechanism, the two types of notation used in the tables were established.

Plastic and elastomeric materials are compounded by the manufacturer. Properties of the materials produced can vary from manufacturer to manufacturer. By compounding, it is possible to improve specific mechanical/physical properties, but usually at the expense of another property. Consequently, materials that have been produced to improve a mechanical property may have had their ability to resist corrosion reduced. Since all plastic or elastomeric materials produced may not have the corrosion resistance indicated in the charts, the manufacturer of the material to be used should be consulted. The same reasoning applies to the physical/mechanical properties required for the application.

A word of caution should also be given regarding temperatures. The table shows only the resistivity to corrosive attack at various temperatures. Although the material may be corrosion-resistant at a specific temperature, this does not mean that the physical/mechanical properties would be satisfactory at these temperatures. These must be investigated at the operating temperature to ensure that the material has the proper mechanical strength for the application.

Using the Tables

The tables are arranged alphabetically according to corrodent. Unless otherwise noted, the corrodent is considered pure in the case of liquids, or a saturated aqueous solution in the case of solids. All percentages shown are by weight.

There are four pages for each corrodent: one for the resistance to metals; one for the resistance to nometallic materials, coatings, and mortars; one for the resistance to plastics; and one for the resistance to elastomers, linings, and fabrics.

TABLE NOTATION

Since corrosion is a function of temperature, the tables indicate the suitability of each material at varying temperatures. Symbols used to designate specific corrosion rates are shown on the bottom of the metals pages. The use of the temperature scale is explained by the following example.

ACETIC ACID 80%

	°C	15	26	38	49	60	71	82	93	104	116	127	138	149	160	171	182	193	204	216	227	238	249	260	271	282	293
METALS	°F	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560
MONEL		E			G																						
STAINLESS STEELS																											
Type 316		E		G				S			U																

From the sample table, it is seen that in the presence of an 80% solution of acetic acid, monel has a corrosion rate varying with temperature rated as follows:

- From 60 to 120°F, excellent (E): < 2 mils penetration/year.
- From 120 to 210°F, good (G): < 20 mils penetration/year.
- There are no data for temperatures beyond 210°F.

Type 316 stainless steel has a corrosion rate for the same corrodent varying with temperature rated as follows:

- From 60 to 100°F, excellent (E): <2 mils penetration/year.
- From 100 to 180°F, good (G): <20 mils penetration/year.
- From 180 to 240°F, satisfactory (S): <50 mils penetration/year.
- Above 240°F, unsatisfactory (U): >50 mils penetration/year.

Nonmetallics are only rated as resistant (R) or unsatisfactory (U), because they do not exhibit a useful corrosion rate, as explained previously.

Other Notation

Further information regarding the corrosion of specific materials by certain corrodents is provided by the following symbols. In the tables, the symbols follow the applicable material or corrodent name.

Symbol	Meaning
1	Material is subject to pitting.
2	Material is subject to stress cracking.
3	Material is subject to crevice attack.
4	Not for use with carbonated beverages.
5	Material should be passivated.
6	Alkaline.
7	Acid free.
8	Acid free and passivated.
9	Material is subject to intergranular corrosion.
10	Synthetic veil or surfacing mat should be used.
11	Material will cause stress cracking in many polyethylenes. A stress crack-resistant, high molecular weight polyethylene must be used.
12	Material is subject to stress cracking when wet.
ALL	Data applies to all concentrations.
ELC	Material is low-carbon grade.
SAT	Solution is saturated.

General Notes

- Incolloy category is applicable to grades 800 and 825 only, unless otherwise specified.

- Inconel category is applicable to grade 600, unless otherwise specified.
- The mortars specified are for use fully immersed or subject to constant flow.
- The coatings specified are for use fully immersed or for wet spills or wet fumes.
- There are many epoxy formulations. Where epoxy is shown as being a satisfactory material of construction, it indicates that there is a suitable formulation. Manufacturers should be consulted for the suitability of their specific formulation.
- See Appendix 3 for plating solution compositions.

READING THE TEMPERATURE SCALE

When using the tables, note that the vertical lines refer to temperatures midway between the temperatures cited (see the sample table below). Thus, aluminum is corroded by pyridine at a rate less than 20 mils/year between 60 and 350°F. Brass, carbon steel, and copper have the same corrosion rate between the temperatures of 60 and 210°F, 120°F, and 80°F, respectively.

When a material is indicated to be unsatisfactory at a specific temperature, it is also unsatisfactory at all temperatures above the one shown. A blank in the chart indicates that no data are available.

PYRIDINE

	°C	15	26	38	49	60	71	82	93	104	116	127	138	149	160	171	182	193	204	216	227	238	249	260	271	282	293
METALS	°F	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560
ADMIRALTY BRASS																											
ALUMINUM		G																									
ALUMINUM BRONZE																											
BRASS		G																									
BRONZE																											
CARBON STEEL		G																									
COLUMBIUM (NIOBIUM)																											
COPPER		G																									
HASTELLOY B/B-2																											
HASTELLOY C/C-276																											

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