

Corrosion of Lead and Lead Alloys

Revised by Safaa J. Alhassan, International Lead Zinc Research Organization, Inc.

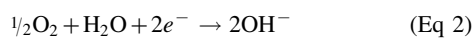
LEAD has such a successful record of service in exposure to the atmosphere and to water that its resistance to corrosion by these media is often taken for granted. Underground, thousands of kilometers of lead-sheathed cable and lead pipe give reliable long-term performance all over the world. In the chemical industry, lead is used in the corrosion-resistant equipment necessary for handling many chemicals. Batteries account for the largest use of lead and are the source of most recycled lead. General information on compositions, properties, and applications can be found in the article "Lead and Lead Alloys" in *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2 of *ASM Handbook*, 1990.

The Nature of Lead Corrosion

The corrosion of lead in aqueous electrolytes is an electrochemical process. The metal either enters the solution at anodic sites as metallic cations or is converted anodically to solid compounds. Both corrosion reactions can be represented by the reaction:



This oxidation reaction (standard oxidation potential, $E^\circ = 0.126 \text{ V}$), which takes place at anodic sites, is accompanied by a reduction of some constituent in the electrolyte at cathodic sites. In neutral salt solutions, the cathodic reaction is the reduction of dissolved oxygen:



In acid solutions free of oxygen, the corresponding cathodic reaction is:



The rate of corrosion is a function of the current flowing between the anodes and cathodes of the corrosion cell. Many factors and conditions can initiate or influence this flow of current. In the corrosion of a single metal, such as lead, local anodes and cathodes may be set up as a result of inclusions, inhomogeneities, stress variations, and differences in temperature. In galvanic corrosion, the anodic and cathodic sites are on

different metals, with the less noble metal (anode) corroding in preference to the more noble metal (cathode).

In most environments, lead is cathodic to steel, aluminum, zinc, cadmium, and magnesium and therefore will accelerate the corrosion of these metals. With titanium, copper, silver, and passivated stainless steels, lead is the anode of the cell and suffers accelerated attack. In either case, the rate of corrosion is governed by the difference in potential between the two metals, the ratio of their areas, and their polarization characteristics.

The corrosion rate of lead is usually under anodic control, because the most important determinant generally is the solubility and other physical characteristics of the corrosion products formed at anodic sites. Most of these products are relatively insoluble lead salts that are deposited on the lead surface as impervious films, which tend to stifle further attack. The formation of such insoluble protective films is responsible for the high resistance of lead to corrosion by sulfuric (H_2SO_4), chromic (H_2CrO_4), and phosphoric (H_3PO_4) acids.

In general, anything that damages the protective film increases the corrosion rate. Factors that help create or strengthen the film reduce the corrosion rate. Therefore, the life of lead-protected equipment can be extended, for example, by washing it with film-forming aqueous solutions containing sulfates, carbonates, or silicates. This procedure is suggested for protecting lead when it will be in contact with corrosives that do not form protective films.

Forms of Corrosion. The corrosion of lead can take many forms. Lead exposed to the usual type of atmospheric attack will corrode uniformly. Pitting will occur under conditions of partial passivity or cavitation, which is the formation and collapse of gas bubbles at a liquid/metal interface.

In some cases, a combination of corrosion and other forms of deterioration, such as erosion, fatigue, and fretting, will cause damage much more severe than that caused by each form of attack working independently. Another type of accelerated corrosion can occur when lead is in contact with a corrosive environment and is subjected to a continuous load exceeding its creep strength. The process of creep will

continually expose fresh surface to the corroding environment.

Intergranular corrosion is another form of attack on lead. It occurs at grain boundaries of lead generally in the cast form and can cause a significant loss in strength.

It is evident that the specific rate and form of corrosion that occur in a particular situation depend on many complex variables. However, in each of the four major environments discussed subsequently—water, atmosphere, underground, and chemical—certain factors have a determining influence on what form and rate lead corrosion will have.

Corrosion in Water

Distilled water free of oxygen and carbon dioxide (CO_2) does not attack lead. Distilled water containing CO_2 but not oxygen also has little effect on lead. The corrosion behavior of lead in distilled water containing dissolved CO_2 and dissolved oxygen depends on CO_2 concentration. This dependency, which causes many different reactions to take place in a narrow range of concentration, explains the contradictory nature of much of the corrosion data reported in the literature.

For example, lead steam coils that handle pure water condensate are not severely corroded in systems in which all condensate is returned to the boiler and negligible makeup water is used. However, if makeup water is used, dissolved oxygen can be introduced to the condensate, and corrosion can be severe. Carbon dioxide can also be generated from the breakdown of carbonates and bicarbonates in boiler water, decreasing the severity of corrosion of lead. The oxygen level in the makeup water is usually controlled by adding oxygen scavengers, such as hydrazine or sodium sulfite.

In general, the corrosion rate in natural and domestic waters depends on the degree of water hardness, which is primarily caused by calcium and magnesium salts in the water. However, environmental regulations do not permit the use of lead in the drinking water supply system despite the very low corrosion rate of lead and lead alloys in these environments. Water hardness in the form of salts, if present in at least

moderate amounts (>125 ppm), forms films on lead that adequately protect it against corrosive attack. Silicate salts present in the water increase both the hardness and the protective value of the film. In contrast, nitrate and chloride ions either interfere with the formation of the protective film or penetrate it; thus, they increase corrosion.

In soft, aerated natural and domestic waters, the corrosion rate depends on both the hardness and the oxygen content of the water. When water hardness is less than 125 ppm, corrosion rate, like the rate in distilled water, depends on the relative proportions of dissolved CO₂ and dissolved oxygen. Potable waters, which in the United States have a zero maximum containment level, often have hardness below 125 ppm and often contain considerable amounts of CO₂ and oxygen; thus, lead cannot be used for pipe or containers that handle potable waters. The U.S. Environmental Protection Agency calls for an action level of 0.015 mg/L of lead in drinking water. This problem of contamination limits the use of lead in such applications, even though from a service point of view, the corrosion rate is negligible.

The corrosion rates of chemical lead (99.9% Pb) in several industrial and domestic waters are presented in Table 1. It should be noted that corrosion rate is relatively low, even where water hardness is below 125 ppm. A corrosion rate for a freshwater is also included among the data for seawater in Table 2.

The corrosion of lead in seawater is relatively slight and may be retarded by incrustations of lead salts. Data on the performance of lead in seawater at several locations are given in Table 2. Comparison of two of the entries in this table shows that at the same tropical location (Panama), the corrosion rate of lead in freshwater is approximately one-fourth the rate in seawater.

Extensive service experience and laboratory testing have indicated that the corrosion rate of lead is generally quite low in a wide variety of waters. The only major applications in which lead cannot be used are those involving some pure waters containing oxygen and soft natural waters, especially if contamination is of concern. In contrast, as discussed previously, addition of calcium and magnesium salts further enhances the resistance of lead to corrosion by water.

Atmospheric Corrosion

In most of its forms, lead exhibits consistent durability in all types of atmospheric exposure, including industrial, rural, and marine (Table 3). The corrosion rate of lead in industrial environment (Altoona, PA) is 0.6 to 0.7 μm/yr (0.02 to 0.03 mils/yr) and 1.0 to 1.3 μm/yr (0.04 to 0.05 mils/yr) in marine environment (Kure Beach, NC). The corrosion rate of lead in a rural environment (State College, PA) is 1.0 to 1.4 μm/yr (0.04 to 0.06 mils/yr) in 2 years and 0.33 to 0.35 μm/yr (0.013 to 0.014 mils/yr) in 20 years. These three atmospheric environments are

distinct because each involves different factors that promote corrosion. In rural areas, which are relatively free of pollutants, the only important environmental factors influencing corrosion rate

are humidity, rainfall, and air flow. However, near or on the sea, chlorides entrained in marine air often exert a strong effect on corrosivity. In industrial environments, sulfur oxide gases and

Table 1 Corrosion of chemical lead in industrial and domestic waters

Total immersion

Type of water	Temperature		Aeration	Agitation	Corrosion rate	
	°C	°F			μm/yr	mils/yr
Condensed steam, traces of acid	21–38	70–100	None	Slow	21.59	0.85
Mine water						
pH 8.3, 110 ppm hardness	20	68	Yes	Slow	6.60	0.26
160 ppm hardness	19	67	Yes	Slow	7.11	0.28
110 ppm hardness	22	72	Yes	Slow	6.35	0.25
Cooling tower water, oxygenated, from Lake Erie	16–29	60–85	Complete	None	134.6	5.3
Los Angeles aqueduct water, treated with chlorine and copper sulfate		Ambient	...	150 mm/s (0.5 ft/s)	9.65	0.38
Spray cooling water, chromate treated	16	60	Yes	...	9.4	0.37

Table 2 Corrosion of lead in natural waters

Location	Type of water	Type of test	Agitation	Corrosion rate		Ref
				μm/yr	mils/yr	
Bristol Channel	Seawater	Immersion approx. 93% of the time	...	12.7	0.50	1
Southampton Docks	Seawater	Half tide level	...	2.79	0.11	2
Gatun Lake, Panama	Tropical freshwater	Immersion	None	2.03	0.08	3
Fort Amador, Panama	Tropical Pacific Ocean	Immersion	Flowing(a)	9.14	0.36	4
Fort Amador, Panama	Tropical Pacific Ocean	Mean tide level	Flowing(a)	5.08	0.20	4
San Francisco Harbor	Seawater	Mean tide level	Flowing	10.67	0.42	4
Port Hueneme Harbor, CA	Seawater	Immersion	Flowing(b)	5.59	0.22	5
Kure Beach, NC	Seawater	Immersion	...	15.24	0.60	4

(a) At 150 mm/s (0.5 ft/s). (b) At 60 mm/s (0.2 ft/s)

Table 3 Corrosion of lead in various natural outdoor atmospheres

Location	Type of atmosphere	Duration of test, years	Type of lead	Corrosion rate		Ref
				μm/yr	mils/yr	
Altoona, PA	Industrial	10	Chemical	0.737	0.029	6, 7
			Pb-1Sb	0.584	0.023	6, 7
New York City	Industrial	20	Chemical	0.381	0.015	6, 7
			Pb-1Sb	0.330	0.013	6, 7
Sandy Hook, NJ	Seacoast	20	Chemical	0.533	0.021	6, 7
			Pb-1Sb	0.508	0.020	6, 7
Key West, FL	Seacoast	10	Chemical	0.584	0.023	6, 7
			Pb-1Sb	0.559	0.022	6, 7
LaJolla, CA	Seacoast	20	Chemical	0.533	0.021	6, 7
			Pb-1Sb	0.584	0.023	6, 7
State College, PA	Rural	20	Chemical	0.330	0.013	6, 7
			Pb-1Sb	0.356	0.014	6, 7
Phoenix, AZ	Semiarid	20	Chemical	0.102	0.004	6, 7
			Pb-1Sb	0.308	0.012	6, 7
Kure Beach, NC (25 m, or 80 ft site)	East coast, marine	2	Chemical	1.321	0.052	8
			Pb-6Sb	1.041	0.041	8
Newark, NJ	Industrial	2	Chemical	1.473	0.058	8
			Pb-6Sb	1.067	0.042	8
Point Reyes, CA	West coast, marine	2	Chemical	0.914	0.036	8
			Pb-6Sb	0.660	0.026	8
State College, PA	Rural	2	Chemical	1.397	0.055	8
			Pb-6Sb	0.991	0.039	8
Birmingham, England	Urban	7	99.96% Pb	0.939	0.037	9
			Pb-1.6Sb	0.102	0.004	9
Wakefield, England	Industrial	1	99.995% Pb	1.879	0.074	9
Southport, England	Marine	1	99.995% Pb	1.778	0.070	9
Bourneville, England	Suburban	1	99.995% Pb	1.956	0.077	9
Cardington, England	Rural	1	99.995% Pb	1.422	0.056	9
Cristobal, Panama	Tropical, marine	8	Chemical	1.346	0.053	3
Miraflores, Panama	Tropical, marine	8	Chemical	0.762	0.030	3

the minerals in solid emissions change the patterns of corrosion behavior considerably. However, the protective films that form on lead and its alloys are so effective that corrosion is insignificant in most natural atmospheres. The extent of this protection is demonstrated by the survival of lead roofing and auxiliary products after hundreds of years of atmospheric exposure. In fact, the metal is preserved permanently if these films are not damaged (Ref 10). A detailed review (Ref 11) reported that the aggressiveness and abundance of various potentially interacting anions produce a composite diagram of lead corrosion reactions and products for atmospheric laboratory exposures of lead involving H₂S, SO₂, CO₂, and Cl₂ gases. Depending on the characteristic of the environment, atmospheric corrosion products on lead customarily include anglesite (PbSO₄) and cerussite (PbCO₃). In addition to the products reported for exposed lead samples, it would not be surprising to find lead oxalates where oxalic acid is abundant, such as in fog droplets in urban areas (Ref 11).

Furthermore, lead runoff is an important issue because of the possible adverse effect on human health. Modern structures may use considerable quantities of lead for aesthetic purposes in the form of leaded-copper sheeting.

An analysis of precipitation runoff from high-purity lead sheets at unpolluted sites in Newport (marine) and Albany (rural), OR, found lead levels of 0.7 and 3.7 mg/L, respectively (Ref 12). The study also showed that lead corrosion films consisted mainly of lead carbonate and lead hydroxy carbonate that showed extensive cracking.

Antimonial lead, such as UNS 52760 (Pb-2.75Sb-0.2Sn-0.18As-0.075Cu), exhibits approximately the same corrosion rate in atmospheric environments as chemical lead (99.9% commercial-purity lead). However, the greater hardness, strength, and resistance to creep of antimonial lead often make it more desirable for use in specific chemical and architectural applications. The ability of some antimonial leads to

retain this greater mechanical strength in atmospheric environments has been demonstrated in exposure tests in which sheets containing 4% Sb and smaller amounts of arsenic and tin were placed in semirestricted positions for 3 years. They showed less tendency to buckle than chemical lead, indicating that their greater resistance to creep had been retained.

Painting of lead coatings, especially terne metal (a coating containing 8 to 12% Sn, bal Pb),

further raises their resistance to corrosion in outdoor environments. Terne metal has such good paint retention that one coat will far outlast two separate coats on plain steel.

Corrosion in Underground Ducts

Lead is extensively used in the form of sheathing for power and communications cables because of its impermeability to water and its excellent resistance to corrosion in a wide variety of soil conditions. Cables are either buried directly in the ground or installed in ducts or conduits made of such materials as cement or vitrified clay.

Severe corrosion of lead in underground service (in ducts or directly in the soil) is the exception rather than the rule. However, because repair or replacement of underground components is difficult and expensive, proper corrosion protection is recommended in any underground

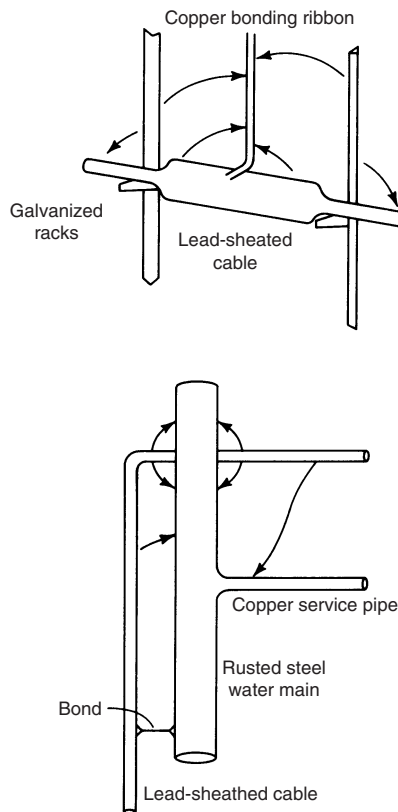


Fig. 1 Corrosion caused by galvanic coupling. Arrows indicate direction of current flow. Source: Ref 2

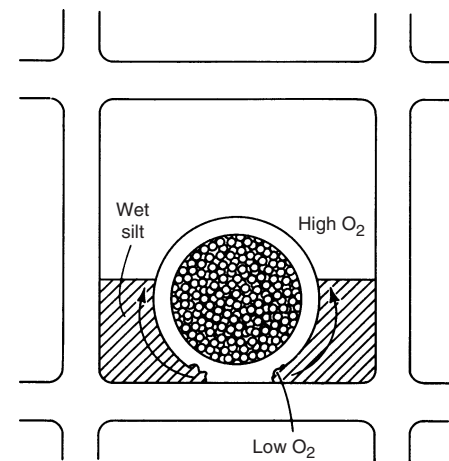


Fig. 2 Corrosion caused by differential aeration in a duct. Arrows indicate direction of current flow. Source: Ref 2

Table 4 Corrosion of lead alloys in various soils

Maximum exposure time: 11 years

Type of soil	Chemical lead(a)				Tellurium lead(b)				Antimonial lead(c)			
	Corrosion rate		Max pit depth		Corrosion rate		Max pit depth		Corrosion rate		Max pit depth	
	µm/yr	mils/yr	µm	mils	µm/yr	mils/yr	µm	mils	µm/yr	mils/yr	µm	mils
Cecil clay loam	<2.54	<0.1	457	18	<2.54	<0.1	406	16	<2.54	<0.1	229	9
Hagerstown loam	<2.54	<0.1	787	31	<2.54	<0.1	762	30	<2.54	<0.1	406	16
Lake Charles clay	7.62	0.3	2540	100	10.16	0.4	2718	107	10.16	0.4	2642	104
Muck	7.62	0.3	1321	52	7.62	0.3	1346	53	7.62	0.3	1295	51
Carlisle muck	5.08	0.2	508	20	5.08	0.2	533	21	2.54	0.1	305	12
Rifle peat	<2.54	<0.1	838	33	<2.54	<0.1	584	23	<2.54	<0.1	711	28
Sharkey clay	7.62	0.3	1778	70	7.62	0.3	1854	73	10.16	0.4	2261	89
Susquehanna clay	<2.54	<0.1	864	34	2.54	0.1	1016	40	2.54	0.1	356	14
Tidal marsh	<0.25	<0.01	305	12	<0.25	<0.01	203	8	<0.25	<0.01	152	6
Docas clay	<2.54	<0.1	635	25	<2.54	<0.1	432	17	<2.54	<0.1	483	19
Chino silt loam	<2.54	<0.1	381	15	<2.54	<0.1	508	20	<2.54	<0.1	178	7
Mohave fine gravelly clay	<2.54	<0.1	610	24	<2.54	<0.1	584	23	2.54	<0.1	406	16
Cinders	7.62	0.3	2159	85	7.62	0.3	1549	61	10.16	0.4	1168	46
Merced silt loam	<2.54	<0.1	610	24	<2.54	<0.1	406	16	<2.54	<0.1	229	9

(a) 0.056 Cu, 0.002 Bi, 0.001 Sb. (b) 0.08 Cu, 0.01 Sb, 0.043 Te. (c) 0.036 Cu, 5.3 Sb, 0.016 Bi. Source: Ref 19

service. Although the discussion that follows is based on preventive methods used for lead-sheathed cables, it is directly applicable in many ways to the underground behavior of other lead products, such as chemical service pipe.

The environment within ducts is often quite complex (Ref 10). It can include combinations of highly humid manhole and soil atmospheres, free lime leached from concrete, and alkalis formed by the electrolysis of salts in the water that seeps

into ducts. Some of the factors involved in the corrosion of lead cable sheathing and how they relate to cable assembly and installation are discussed in Ref 13. Their influence in initiating or accelerating corrosion is described in Ref 13, with simple sketches used for illustration. Two of these factors—galvanic coupling and differential aeration—are discussed as follows.

Galvanic Coupling. Figure 1 illustrates two typical examples of contact between lead and other metals. In the presence of an electrolyte, such a dissimilar-metal couple forms a galvanic cell in which the more anodic metal is corroded. A difference in potential sufficient to cause corrosion may also arise when the surface of the lead is scratched to expose bright, active metal. In such cases, the exposed metal is the anode and is attacked.

Differential Aeration. Figure 2 illustrates differential-aeration corrosion. In this type of corrosion cell, areas exposed to low oxygen concentration tend to become anodic to areas exposed to higher oxygen concentrations. As shown, the amount of air able to penetrate the silt and reach the crevice where the cable sheath and the duct meet is less than the amount available at the upper surface of the sheath; this results in corrosion.

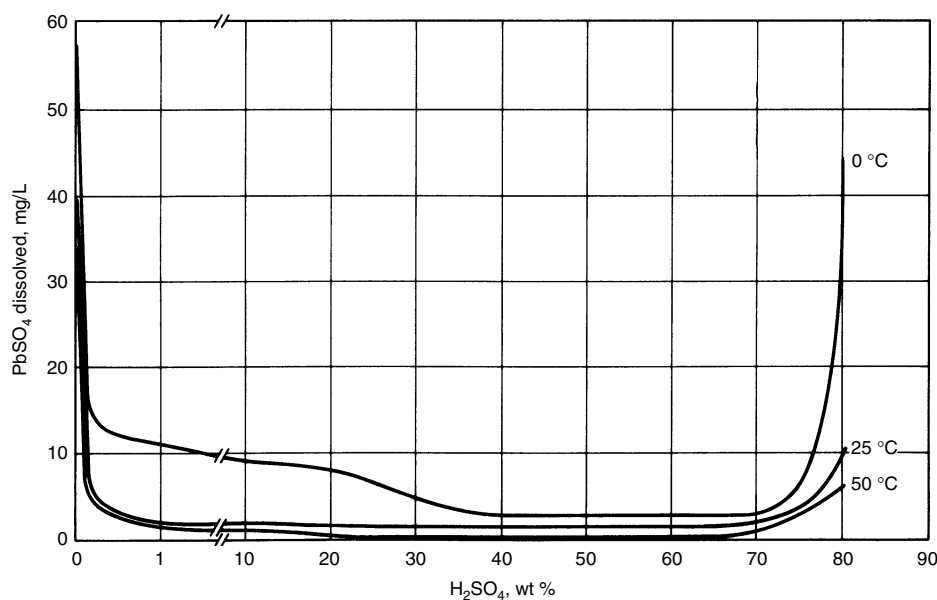
An actual example of differential-aeration corrosion is described in Ref 14. Lead-sheathed cable was pressed tightly against the inner surface of a tile duct, and water formed a meniscus extending from the sheathing surface to the tile. The area that was pressed against the tile did not corrode. However, an adjacent area, where the water was farthest from contact with air, corroded severely. The lead surface in contact with water closer to the air in the duct was the cathode.

Alkalinity is another factor that causes the corrosion of cable sheathing (Ref 15). Sheathing on cable installed in continuous concrete or asbestos cement ducts in concrete tunnels under waterways was found to be severely corroded. Analysis of water samples from these locations revealed that the corrosion had resulted from the presence of up to 1000 ppm of hydroxides.

Table 5 Solubility of lead compounds in water

Lead compound	Formula	Temperature		Solubility, kg/m ³
		°C	°F	
Acetate	Pb(C ₂ H ₃ O ₂) ₂	20	68	433
Bromide	PbBr ₂	20	68	8.441
Carbonate	PbCO ₃	20	68	0.0011
Basic carbonate(a)	2PbCO ₃ , Pb(OH) ₂	...	...	Insoluble
Chlorate	Pb(ClO ₃) ₂ , H ₂ O	18	64	0.513
Chloride	PbCl ₂	20	68	9.9
Chromate	PbCrO ₄	25	77	0.000058
Fluoride	PbF ₂	18	64	0.64
Hydroxide	Pb(OH) ₂	18	64	0.155
Iodide	PbI ₂	18	64	0.63
Nitrate	Pb(NO ₃) ₂	18	64	565
Oxalate	PbC ₂ O ₄	18	64	0.0016
Oxide	PbO	18	64	0.017
Orthophosphate	Pb ₃ (PO ₄) ₂	18	64	0.00014
Sulfate	PbSO ₄	25	77	0.0425
Sulfide	PbS	18	64	0.1244
Sulfite(a)	PbSO ₃	...	...	Insoluble

(a) At room temperature. Source: Ref 21



H ₂ SO ₄ , wt%	PbSO ₄ , dissolved, mg/L, at:		
	0 °C (32 °F)	25 °C (75 °F)	50 °C (120 °F)
0	33.0	44.5	57.7
0.005	8.0	10.0	24.0
0.01	7.0	8.0	21.0
0.10	4.6	5.2	13.0
1.0	1.8	2.2	11.3
10.0	1.2	1.6	9.6
20.0	0.5		8.0
30.0	0.4	1.2	4.6
60.0	0.4	1.2	2.8
70.0	1.2	1.8	3.0
75.0	2.8	3.0	6.6
80.0	6.5	11.5	42.0

Fig. 3 Solubility of lead sulfate in sulfuric acid

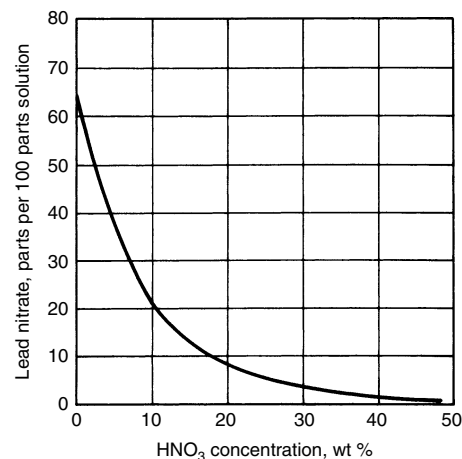


Fig. 4 Solubility of lead nitrate in nitric acid

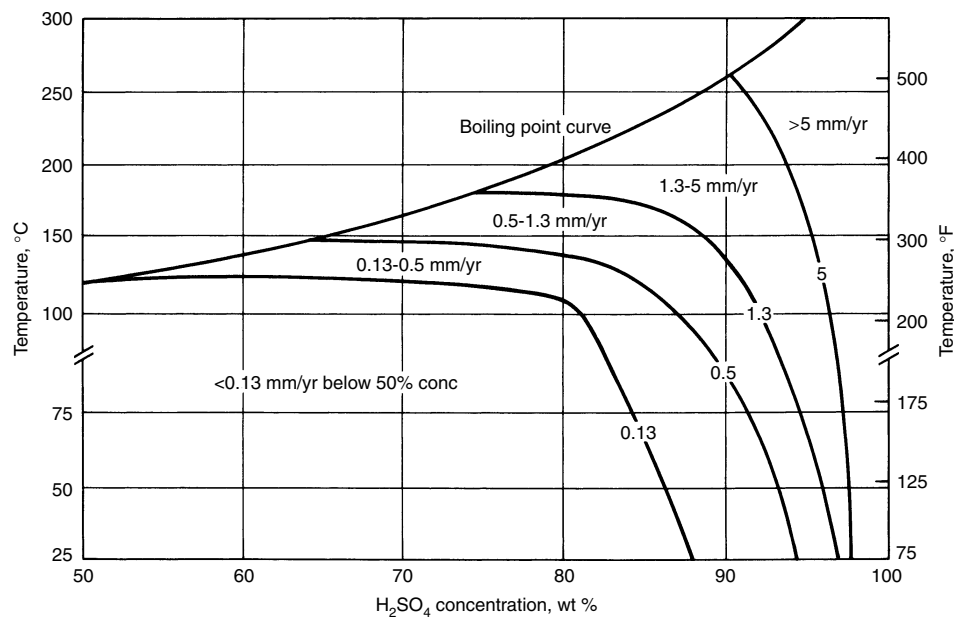


Fig. 5 Corrosion rate of lead in H_2SO_4 . Source: Ref 22

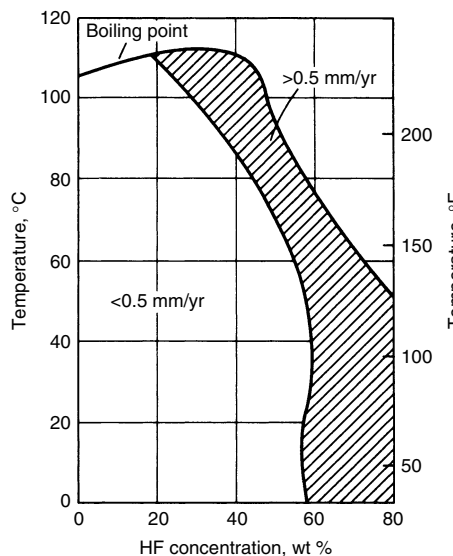


Fig. 6 Resistance of lead to corrosion in air-free hydrofluoric acid

Table 6 Corrosion of chemical lead in commercial phosphoric acid at 21 °C (70 °F)

Solution	Corrosion rate	
	$\mu\text{m}/\text{yr}$	mils/yr
20% H_3PO_4	86.4	3.4
30% H_3PO_4	124.5	4.9
40% H_3PO_4	144.8	5.7
50% H_3PO_4	162.6	6.4
85% H_3PO_4	40.6	1.6
80% H_3PO_4 (a)	325.1	12.8

(a) Pure grade

These alkaline water samples (pH 10.9 to 12.2) contained mainly calcium hydroxide. Sodium hydroxide was also found in some tunnels.

Table 7 Corrosion of lead in hydrochloric acid at 24 °C (75 °F)

HCl concentration, %	Chemical lead		6% antimonial lead	
	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr
1	610	24	840	33
5	410	16	510	20
10	560	22	1090	43
15	790	31	3810	150
20	1880	74	4060	160
25	4830	190	5080	200
35(a)	8890	350	13,720	540

(a) Commercially concentrated HCl

Table 8 Corrosion of lead in hydrochloric acid-ferric chloride mixtures at 24 °C (75 °F)

Solution	Chemical lead		6% antimonial lead	
	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr
5% HCl + 5% $FeCl_3$	711	28	940	37
10% HCl + 5% $FeCl_3$	1041	41	1930	76
15% HCl + 5% $FeCl_3$	2235	88	4064	160
20% HCl + 5% $FeCl_3$	3810	150	4826	190

Table 9 Corrosion of lead in nitric acid

HNO ₃ solution, %	Corrosion rate			
	24 °C (75 °F)		50 °C (122 °F)	
	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr
1	3556	140	15,240	600
5	41,910	1650	46,990	1850
10	86,360	3400	88,646	3490

The source of the calcium hydroxide was incompletely cured concrete. Electrolysis of solutions of deicing salts that had seeped into the

tunnels was believed to be the source of sodium hydroxide. The buildup in concentration occurred because seepage water was not being removed (the ducts had been designed to function without removal of seepage water). Proper drainage and use of completely cured, impervious concrete were suggested as corrective measures.

The process of passive film formation on lead in alkaline solutions and its breakdown were examined (Ref 16) and it was found that the anodic polarization curves exhibit three peaks that correspond to PbO , Pb_3O_4 , and PbO_2 prior to the oxygen evolution reaction. It was also found that the addition of NO_3^- ions enhances the anodic dissolution of PbO and, at certain pitting potentials, causes the breakdown of the passivation layer itself. The critical potential was found to decrease linearly with both the logarithmic concentration of nitrate and temperature, while increasing the alkali concentration or the potential scan rate increased the pitting potential.

Stray currents can cause severe corrosion of lead pipe or lead cable sheathing. Stray currents are those that follow paths outside intended circuits. They may also be minor earth currents. Stray currents cause corrosion at the point where they leave the metal. Sources of stray currents include electric railway systems, grounded electric direct current power, electric welders, cathodic protection systems, and electroplating plants. Stray alternating currents are much less damaging than stray direct currents.

It has also been found that corrosion of lead cable sheathing in manhole water depends more on the magnitude and polarity of the potential between the ground and the lead sheathing than it does on the natural dissolved salts in the water. Corrosion is at a minimum when the sheathing is cathodic to the ground (Ref 17, 18). Proper grounding prevents this type of corrosion.

Other factors that can initiate the corrosion of lead sheathing include contact with acetic acid (in wooden ducts), microorganisms, and corroded steel-tape armor. Bacterial corrosion usually occurs when aeration is poor and mud, water, or organic matter is present. Bacteria capable of reducing sulfates to sulfides are the principal cause of attack. Microbial decomposition of the hydrocarbons present in cable coatings may also produce organic acids corrosive to lead. Corrosion of lead by corroded steel-tape armor can occur when the oxide coating formed on the steel is cathodic to lead.

Corrosion in Soil

Soils vary widely in physical and chemical characteristics and, consequently, in corrosive effect. More than 200 varieties of soil in the United States have been classified according to texture, color, and natural drainage. The physical properties of soils that most influence the corrosion of lead in underground service are those

that affect the permeability of the soil to air and water, because good drainage tends to minimize corrosion. Soils with coarse textures, such as sands and gravels, permit free circulation of air. Corrosion in such soils is approximately the same as in the atmosphere. Clays and silty soils generally exhibit fine texture and high water-holding capacity and therefore poor aeration and drainage.

Numerous chemical compounds are present in soils, but only those soluble in water play important roles in the corrosion of metals. For example, the calcareous nature of some Indiana soils influences corrosion through alkaline attack or the promotion of bacterial activity.

Considerable corrosion testing of lead and lead alloys in numerous soils has indicated that corrosion rate decreases with increasing particle size and that the distribution of anodic and cathodic areas depends on soil particle size, water activation value of the soil, soil pH, and duration of exposure. Test results also show that lead tends to become passive in soils regardless of water content; however, addition of sodium bicarbonate reactivates it.

The data in Table 4 show that in most soils the average corrosion rate of lead is low—from less than 2.5 to 10 μm (0.1 to 0.4 mil) per year. It should be noted, however, that the depth of pitting is often a more important measure of underground corrosion behavior than corrosion rate.

The most comprehensive investigation of corrosion of metals buried in soils was conducted by the National Bureau of Standards from 1910 to 1955 (Ref 19). This investigation included lead alloy pipe of three different compositions buried in 14 soils. Specimens were removed periodically; maximum exposure time was 11 years (Table 4).

Analysis of the data in Table 4 indicates that, in general, weight lost and maximum pit depth decrease with increasing aeration of the soil. For example, poor aeration caused severely deep pitting of the lead buried in Sharkey clay, in Lake Charles clay, and in cinders, but pitting of pipe buried in the well-aerated Cecil clay loam was shallow.

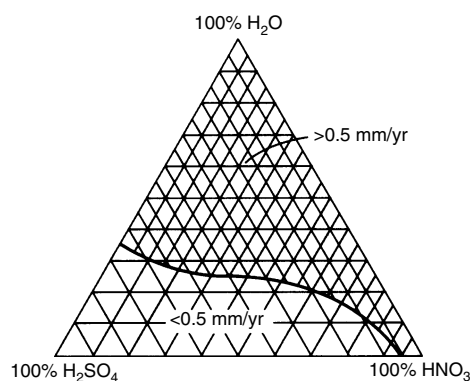


Fig. 7 Corrosion rates of lead in $\text{H}_2\text{SO}_4\text{-HNO}_3\text{-H}_2\text{O}$ mixtures

Resistance to Chemicals

The excellent resistance of lead and lead alloys to corrosion by a wide variety of chemicals is attributed to the polarization of local anodes caused by the formation of a relatively insoluble surface film of lead corrosion products (Ref 20). The extent of protection depends on the compactness, adherence, and solubility of these films.

Solubilities of various lead compounds in water at room temperature are given in Table 5. These data are general indicators of the behavior of lead in solutions that promote the formation of these compounds. The solubility of a lead corrosion product, however, depends on the solution in which the lead is immersed. Therefore, the solubility of that corrosion product in water is not always an adequate indicator of its behavior in another solution. This fact is illustrated by the variation in solubility of lead sulfate (PbSO_4) in H_2SO_4 as acid concentration and temperature change (Fig. 3). The PbSO_4 film is less soluble in H_2SO_4 solutions than it is in water. Solubility

drops to a minimum value at acid concentrations of 30 to 60% and then increases at higher concentrations. At intermediate concentrations, the sulfate film is so insoluble that corrosion is negligible.

Another example of the importance of the solubility relationship of the lead film to its environment is shown in Fig. 4. Lead nitrate ($\text{Pb}(\text{NO}_3)_2$) is quite soluble in dilute and intermediate-strength solutions of nitric acid (HNO_3) at room temperature. Lead is not resistant to corrosion under such conditions. However, above an HNO_3 concentration of 50%, $\text{Pb}(\text{NO}_3)_2$ is only slightly soluble, and lead is quite resistant to attack.

Increases in temperature generally increase corrosion rate (Fig. 3). This effect is primarily due to increases in film solubility.

Galvanic Corrosion. When lead is anodic to a metal to which it is coupled and a firm film develops on the lead, galvanic corrosion of the lead will be negligible. For example, when lead is galvanically connected to a copper or a copper alloy in a H_2SO_4 , H_2CrO_4 , or H_3PO_4 solution,

Table 10 Effect of nitric acid in sulfuric acid on the corrosion of lead at 118 °C (245 °F)

Solution	Chemical lead		6% antimonial lead	
	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr
54% H_2SO_4 + 0% HNO_3	188	7.4	356	14
54% H_2SO_4 + 1% HNO_3	150	5.9	559	22
54% H_2SO_4 + 5% HNO_3	213	8.4	2896	114

Table 11 Corrosion of chemical lead with sulfuric-nitric mixed acids

Solution	Corrosion rate			
	24 °C (75 °F)		50 °C (122 °F)	
	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr
78% H_2SO_4 + 0% HNO_3	25.4	1	50.8	2
78% H_2SO_4 + 1% HNO_3	76.2	3	304.8	12
78% H_2SO_4 + 3.5% HNO_3	91.4	3.6	457.2	18
78% H_2SO_4 + 7.5% HNO_3	101.6	4	889	35

Table 12 Corrosion of lead in hydrochloric acid-sulfuric acid mixtures

Solution	Chemical lead				6% antimonial lead			
	24 °C (75 °F)		66 °C (150 °F)		24 °C (75 °F)		66 °C (150 °F)	
	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr
1% HCl + 9% H_2SO_4	130	5	230	9	130	5	300	12
3% HCl + 7% H_2SO_4	360	14	810	32	530	21	1040	41
5% HCl + 5% H_2SO_4	360	14	1070	42	530	21	1650	65
7% HCl + 3% H_2SO_4	410	16	1140	45	560	22	1880	74
9% HCl + 3% H_2SO_4	460	18	1190	47	760	30	2130	84
5% HCl + 25% H_2SO_4	250	10	560	22	560	22	860	34
10% HCl + 20% H_2SO_4	430	17	1070	42	2030	80	1470	58
15% HCl + 15% H_2SO_4	1040	41	1880	74	2290	90	4570	180
20% HCl + 10% H_2SO_4	2180	86	3050	120	2790	110	4570	180
25% HCl + 5% H_2SO_4	3560	140	4060	160	3810	150	5330	210
5% HCl + 45% H_2SO_4	1580	62	...	...	1350	53	...	...
10% HCl + 40% H_2SO_4	1650	65	...	...	2130	84	...	...
15% HCl + 35% H_2SO_4	1680	66	...	...	3050	120	...	...
20% HCl + 30% H_2SO_4	2130	84	...	...	3300	130	...	...
25% HCl + 25% H_2SO_4	3050	120	...	...	5330	210	...	...

Table 13 Effect of sulfuric acid on the corrosion of lead by fluosilicic acid at 45 °C (113 °F)

Solution	Chemical lead		6% Sb lead	
	$\mu\text{m}/\text{yr}$	mils/yr	$\mu\text{m}/\text{yr}$	mils/yr
5% H_2SiF_6	1346	53	1956	77
5% H_2SiF_6 + 5% H_2SO_4	229	9	356	14
10% H_2SiF_6	1626	64	2921	115
10% H_2SiF_6 + 1% H_2SO_4	2235	88	1930	76
1% H_2SiF_6 + 10% H_2SO_4	102	4	229	9

Table 14 Corrosion of lead in chemical process fluids

Fluids	Temperature		Corrosion rate	
	°C	°F	µm/yr	mils/yr
Sulfation of oils with 25% sulfuric acid (66° Bé) at 60 °C (140 °F)				
Castor	...	...	76.2	3
Tallow	...	...	304.8	12
Olive	...	...	76.2	3
Cod liver	...	...	152.4	6
Neatsfoot	...	...	279.4	11
Fish	...	...	279.4	11
Vegetable	...	...	584.2	23
Peanut	...	...	457.2	18
Sulfonation with 93% sulfuric acid (66° Bé)				
Naphthalene	166	330	1143	45
Phenol	120	248	76.2	3
Washing and neutralization of sulfated and sulfonated compounds				
Sulfated vegetable oil + water wash—neutralized with sodium hydroxide	60	140	228.6	9
Naphthalene sulfonic acid + water wash—neutralized with caustic soda pH 3	70	158	990.6	39
Washing tallow with 2% by wt 60° Bé sulfuric acid	121	250	127	5
Storage of liquid alkyl detergent	...	...	7.62	0.3
Storage of 50% chlorosulfonic acid-50% sulfur trioxide	...	...	15.24	0.6
Mixing tank and crystallizer-saturated ammonium sulfate-5% sulfuric acid solution	47	116	25.4–127	1–5
Splitting				
Olive oil and 0.5% sulfuric acid (66° Bé)	88	190	279.4	11
Storage of split fatty acids	...	...	Liquid 20.32	Liquid 0.8
Storage of split fatty acids	...	...	Liquid level 304.8	Liquid level 12
Extraction of aluminum sulfate from alumina				
Bauxite + sulfuric acid—boiling	...	...	Liquid 406.4	Liquid 16
Bauxite + sulfuric acid—boiling	...	...	Vapor 127	Vapor 5
Alum evaporator	116	240	76.2	3
Tank for dissolving alum paper mill	49	120	406.4	16
Storage of 24% alum solution	...	...	15.24	0.6
Dorr settling tank				
19.5 sulfuric acid, 20% ferrous sulfate, 10% titanium oxide as TiSO ₄	70	158	254	10
Evaporator				
Nickel sulfate solution	100	212	152.4	6
Zinc sulfate solution	107	225	152.4	6
Ammonium sulfate production				
Solution-saturated ammonium sulfate + 5% sulfuric acid	47	116	Mixing tank 25.4	Mixing tank 1
Solution-saturated ammonium sulfate + 5% sulfuric acid	47	116	Crystallizer 127	Crystallizer 5
Acid washing				
Lube oil-treatment with 25% sulfuric acid	104	220	635	25
Sludge oil + 15% sulfuric acid-steam treatment	...	...	508	20
Benzol (crude)-treatment with 3% sulfuric acid washed with water, neutralized with lime	60	140	152.4	6
Tar oil-treatment with 25% sulfuric acid, washed with water, neutralized with sodium hydroxide	77	170	609.6	24
Wet acid gases from regeneration of sulfuric acid	121	250	152.4	6
Polymerization				
Polymerization of butenes with 72% sulfuric acid	80	175	12.7	0.5
Polymerization of butenes with 72% sulfuric acid	80	175	356 pits	14 pits
Viscose rayon spinning bath				
Evaporator—6% sulfuric acid, 17% sodium sulfate, 30% other inorganic sulfates	40	104	127	5
Evaporator—concentrated bath of 20% sulfuric acid, 30% sodium sulfate	55	130	101.6	4
Vapors from spin bath evaporator	49	120	127	5
Spinning bath drippings	46	115	203.2	8
Storage-reclaimed spinning bath liquor	...	...	50.8	2
Pickling solution				
Brass and copper-sulfuric acid + 5% cupric sulfate	71	160	127	5

Source: Ref 23

the lead is protected by a firm film even though it is the anode in the galvanic cell. However, when the other metal is the anode and forms a protective film, galvanic corrosion of the lead may occur, and it is sometimes severe. Aluminum or magnesium will be severely corroded if coupled with lead in the presence of an electrolyte. If lead is coupled with Monel in a 6% H₂SO₄ solution, corrosion of the Monel will be accelerated.

A factor to be kept in mind is that environmental changes can reverse the galvanic positions of the two metals. For example, iron is anodic to lead in acids and cathodic to it in alkalis.

In general, galvanic corrosion of lead is significant only when the lead is coupled with a metal to which it is anodic, when an electrolyte is present, and when a firm film cannot be maintained; corrosion of metals anodic to lead seldom occurs. When galvanic corrosion of either lead or the dissimilar metal does occur, it is unlikely to be severe, because lead occupies a central position in the galvanic series.

Physical variables also influence the corrosion rate of lead in many situations. For example, if the flow velocity of a solution is above a critical point, it can completely erode the protective film, leaving only a clean lead surface exposed for continued attack. This is demonstrated by the rapid increase in corrosion of lead in 20% H₂SO₄ at velocities greater than 1.5 m/s (300 ft/min). The presence of foreign insoluble matter further aggravates this condition.

Fatigue stresses may also break the protective film on lead, repeatedly exposing lead to environmental attack. However, applied fatigue stresses no greater than the creep strength of lead do not significantly affect corrosion properties.

Quantitative Corrosion Data. It is important to remember when evaluating quantitative corrosion data that lead weighs more per unit of volume and is normally used in greater thicknesses than most other metals. The effects of these two factors should be considered in evaluating the data presented in this section.

Lead has high corrosion resistance to H₂CrO₄, H₃PO₄, H₂SO₄, and sulfurous (H₂SO₃) acids and is widely used in their manufacture and handling. Lead satisfactorily resists all but the most dilute solutions of H₂SO₄. It performs well at acid concentrations up to 95% at ambient temperatures, up to 93% at 150 °C (302 °F), and up to 85% at 220 °C (428 °F) (Fig. 5). Below a concentration of 5%, the corrosion rate increases, but it is still relatively low. In the lower range of acid concentration, antimonial lead is recommended.

Lead exhibits the same excellent corrosion resistance to higher concentrations of H₂CrO₄, H₂SO₃, and H₃PO₄ at elevated temperatures. Lead finds especially wide application in the manufacture of H₃PO₄ from phosphate rock when H₂SO₄ is used in the process. Corrosion rates are low for all acid concentrations up to 85% (Table 6). However, when in pure H₃PO₄ manufactured from elemental phosphorus, lead

shows a higher rate due to the absence of sulfates. The corrosion rate of 6% antimonial lead has been reported to be lower than that of chemical lead in a plant test using a solution containing 32% H₃PO₄, 0.4% H₂SO₄, and 1% chlorides at 88 °C (190 °F). In pure acid manufactured from elemental phosphor, lead corrodes at a higher rate because of the absence of sulfates.

Lead has fair corrosion resistance to dilute hydrochloric acid (HCl) (up to 15%) at 24 °C (75 °F); the corrosion rate increases at higher concentrations and at higher temperatures (Table 7). The presence of 5% ferric chlorides also accelerates corrosion (Table 8).

The resistance of lead to corrosion by hydrofluoric acid (HF) is only fair. However, lead is used to handle HF because it is the only low-priced metal that has adequate corrosion resistance. The corrosion rate in this acid (if it is free of air) is less than 510 µm/yr (20 mils/yr) for a wide range of temperatures and concentrations (Fig. 6).

Nitric, acetic, and formic acids in most concentrations corrode lead at rates high enough to preclude its use in these acids. However, although HNO₃ rapidly attacks lead when dilute, it has little effect at strengths of 52 to 70%. The same is true of HF and acetic acid.

Addition of H₂SO₄ to acids corrosive to lead often lowers the corrosion rate. For example, although HNO₃ in concentrations less than 50% is quite corrosive to lead (Table 9), in the presence of 54% H₂SO₄ the corrosion rate in 1% and 5% HNO₃ is quite low even at 118 °C (245 °F) (Table 10). Other concentrations of H₂SO₄ also lower the corrosion rate in HNO₃ (Table 11). The composition range of mixed H₂SO₄ and HNO₃ solutions for which chemical lead has a corrosion rate of less than 500 µm (20 mils) per year is shown in Fig. 7. Chemical lead is preferred over 6% antimonial lead for handling these mixtures of acids.

The corrosion rates of chemical lead and 6% antimonial lead in HCl and in fluosilicic acid are retarded by the presence of H₂SO₄ (Tables 12 and 13). Data on the corrosion of lead in chemical process fluids containing H₂SO₄ or closely related compounds are presented in Table 14.

Qualitative corrosion data serve to provide guidelines for screening suitable metals for chemical equipment. Laboratory test environments may not always simulate actual plant conditions, and there may be significant variations among plants manufacturing the same product. Therefore, it is often more helpful to be less specific when categorizing the corrosion rates of lead in various chemicals. Table 15 presents such less specific information and should be used only as a guide for determining whether further tests are warranted. Most of the data in Table 15 are for chemical lead. The corrosion rates of different grades of lead in the same chemical all normally fall within the same category. Therefore, no mention is made of variations in corrosion rate for other grades of lead.

Table 15 Corrosion rate of lead in chemical environments

For corrosion rate information on lead in other chemical environments, see the more extensive tables contained in *Lead for Corrosion Resistant Applications—A Guide*, Lead Industries Association, Inc., 295 Madison Avenue, New York, NY, 10017, 1974

Chemical	Temperature		Concentration, %	Corrosion class(a)
	°C	°F		
Acetic acid	24	75	Glacial	B
Acetic anhydride	24	75	...	A
Acetone	24–100	75–212	10–90	A
Alcohol, ethyl	24–100	75–212	10–100	A
Alcohol, methyl	24–100	75–212	10–100	A
Aluminum chloride	24	75	0–10	B
Aluminum potassium sulfate	24–100	75–212	10–20	A
Aluminum potassium sulfate	24–100	75–212	20–100	B
Ammonia	24–100	75–212	10–30	B
Ammonium chloride	24	75	0–10	B
Ammonium hydroxide	27	80	3.5–40	A
Ammonium nitrate	24–49	75–120	10–30	D
Ammonium sulfate	24	75	...	B
Amyl acetate	24	75	80–100	B
Aniline	20	68	...	A
Antimony chloride	24	75	...	C
Arsenic trichloride	100–149	212–300	...	B
Barium chloride	24–100	75–212	10	B
Benzaldehyde	24	75	10–100	D
Benzene	24	75	...	B
Benzoic acid	24	75	...	D
Benzyl alcohol	24–100	75–212	...	B
Benzyl chloride	24–100	75–212	...	B
Beryllium chloride	100	212	...	D
Boric acid	24–149	75–300	10–100	B
Bromine	24	75	...	B
Butyric acid	24	75	10–100	D
Cadmium sulfate	24–100	75–212	10–30	A
Calcium bicarbonate	24	75	...	C
Calcium chloride	24	75	20	A
Calcium fluoride	24–100	75–212	...	B
Calcium nitrate	24	75	10	D
Calcium sulfate	24–100	75–212	10	B
Carbon disulfide	24–100	75–212	...	A
Carbonic acid	24	75	...	D
Cellulose acetate	24	75	...	A
Cellulose nitrate	24–100	75–212	...	B
Chloroacetic acid	24	75	...	B
Chloric acid	24	75	10	D
Chlorine	38	100	...	B
Chloroform	24–62	75–143	...	B
Chromic acid	24	75	...	B
Copper chloride	24	75	10–40	D
Creosote	24	75	90	D
Dichlorobenzene	24–100	75–212	10–100	B
Diethyl ether	24	75	...	B
Dioxane	24–100	75–212	...	B
Ethyl acetate	24–79	75–175	...	B
Ferric ammonium sulfate	24–100	75–212	10–20	A
Ferric chloride	24	75	20–30	D
Ferric sulfate	24–79	75–175	10–20	A
Ferrous chloride	24	75	10–30	C
Ferrous sulfate	24–100	75–212	10	B
Fluosilicic acid	45	113	10	D
Formaldehyde	24–52	75–125	20–100	B
Formic acid	24–100	75–212	10–100	D
Glycerol	24	75	...	B
Hydrazine	24	75	20–100	D
Hydriodic acid	24	75	10–50	D
Hydrobromic acid	24	75	10–70	D
Hydrochloric acid	24	75	0–10	C
Hydrogen peroxide	24	75	10–30	D
Isopropanol	24	75	...	A
Lead acetate	24	75	10–30	D
Lead chloride	24–100	75–212	...	B
Lithium hydroxide	24	75	...	D
Magnesium chloride	24	75	10–100	D

(continued)

(a) The four categories of the table are: A, < 50 µm/yr (< 2 mils/yr); negligible corrosion—lead recommended for use. B, < 500 µm/yr (< 20 mils/yr); practically resistant—lead recommended for use. (When the only information available is that "lead is resistant" to a certain chemical, that chemical was arbitrarily placed in this category.) C, 500–1270 µm/yr (20–50 mils/yr); lead may be used where this effect on life can be tolerated. D, > 1270 µm/yr (> 50 mils/yr); corrosion rate too high to merit any consideration of lead

Table 15 (continued)

Chemical	Temperature		Concentration, %	Corrosion class(a)
	°C	°F		
Magnesium sulfate	24–100	75–212	10–60	B
Mercury	24	75	100	D
Methyl ethyl ketone	24–100	75–212	10–100	B
Nitrobenzene	24–52	75–125	...	B
Oxalic acid	24	75	20–100	D
Phenol	24	75	90	B
Phosphoric acid	24–93	75–200	...	B
Potassium chloride	8	47	0.25–8.0	B
Potassium hydroxide	24–60	75–140	0–50	B
Pyridine	24–100	75–212	10	B
Sodium acetate	25	77	4	B
Sodium bicarbonate	24	75	10	B
Sodium chloride	25	77	0.5–24	A
Sodium hydroxide	26	79	0–30	B
Sodium nitrate	24	75	10	D
Sodium sulfate	24	75	2–20	A
Stannous chloride	24	75	10–50	D
Zinc sulfate	35	95	...	B
Zinc chloride	79	175	25	B

(a) The four categories of the table are: A, <50 $\mu\text{m}/\text{yr}$ (<2 mils/yr): negligible corrosion—lead recommended for use. B, <500 $\mu\text{m}/\text{yr}$ (<20 mils/yr): practically resistant—lead recommended for use. (When the only information available is that “lead is resistant” to a certain chemical, that chemical was arbitrarily placed in this category.) C, 500–1270 $\mu\text{m}/\text{yr}$ (20–50 mils/yr): lead may be used where this effect on life can be tolerated. D, >1270 $\mu\text{m}/\text{yr}$ (>50 mils/yr): corrosion rate too high to merit any consideration of lead

Table 16 Melting characteristics and applications of tin-lead solders

Tin	Lead	Temperature				Uses
		Solidus		Liquidus		
		°C	°F	°C	°F	
2	98	270	518	312	594	Side seams for can manufacturing
5	95	270	518	312	594	Coating and joining metals
10	90	268	514	299	570	...
15	85	226	440	288	550	...
20	80	183	361	277	531	Coating and joining metals, or filling dents or seams in automobile bodies
25	75	183	361	266	511	Machine and torch soldering
30	70	183	361	255	491	...
35	65	183	361	247	477	General-purpose and wiping solder
40	60	183	361	238	460	Wiping solder for joining lead pipes and cable sheaths. For automobile radiator cores and heating units
45	55	183	361	227	441	Automobile radiator cores and roofing seams
50	50	183	361	216	421	General purpose. Most popular of all
60	40	183	361	190	374	Primarily used in electronic soldering applications in which low soldering temperatures are required
63	37	183	361	183	361	Lowest-melting (eutectic) solder for electronic applications

Tin-Lead Solder Alloys

Solders were based on the tin-lead system. Industrial solder alloys contain a combination of materials ranging from 100% Pb to 100% Sn, as demanded by the application. Each alloy has unique melting characteristics and load-carrying and temperature capabilities. Because electronic equipment is not recycled as efficiently as batteries, there are health concerns about discarded electronic equipment in landfills. Initiatives worldwide have sought to eliminate lead in solder for electrical and electronic equipment. There are exceptions where no substitutes are available, and, in some cases, implementation dates have been delayed (Ref 24).

Table 16 gives the melting temperatures of some tin-lead compositions and their respective applications. More detailed information on the compositions and melting characteristics of tin-lead solders can be found in the article “General Soldering” in *Welding, Brazing, and Soldering*, Volume 6 of *ASM Handbook*, 1993. Corrosion-related data of these alloys are also presented in the article “Corrosion of Tin and Tin Alloys” in this Volume.

Applications. Solder alloys containing less than 5% Sn are used for joining tin-plated containers and for automobile radiator manufacture. For automobiles, a small additional amount of silver is usually added to provide extra joint strength at automobile radiator operating

temperatures. Solder alloys of 10Sn-90Pb and 20Sn-80Pb are also used in radiator joints. With compositions between 10Sn-90Pb and 25Sn-75Pb, care must be taken to avoid any kind of movement during the solidification phase to prevent hot tearing in solders with a wide freezing range.

Higher tin content solders at the 25Sn-75Pb and 30Sn-70Pb compositions have lower liquidus temperatures and can be used for joining materials with sensitivity to high temperature or where the wetting characteristics of the tin are important to providing sound soldering joints. Solder alloys in the composition range described previously are usually applicable to industrial products and generally are used in conjunction with inorganic fluxing materials.

The widely used general-purpose solder alloys contain 40 to 50% Sn. These solders are used for plumbing applications, electrical connections, and general soldering of domestic items. The 60Sn-40Pb and 63Sn-37Pb alloys are used most extensively in the electronic industries for both hand soldering and wave or dip applications. Sometimes, silver additions are made to alloys used in the electronics industries to reduce dissolution of silver-base coatings.

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