LION® C-276 alloy

Excellent corrosion-resistance to both oxidizing and reducing media and excellent resistance to localized corrosion attack.

Contents

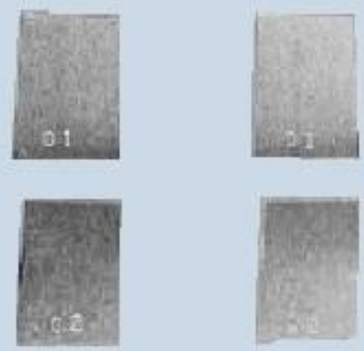
LION® : THE NAME TO TRUST

In aggressive/corrosive service, when nothing else works, many industries have traditionally turned to LION® C-276 alloy. Many years of outstanding performance in a variety of industrial applications have confirmed the advantages of using the alloy. Materials engineers in the chemical processing and other industries have grown accustomed to specifying its high performance based on laboratory testing, field trials and/or prior experience.

Some “generic” alloy N10276 products fail to measure up to the performance industry expects from LION C-276 alloy which is produced via exacting processes, and backed by years of experience in chemistry control, thermal-mechanical processing, testing and qualifications to rigid standards.

UNS N10276 (SOURCE X)		LION® C-276 alloy
MILL ANNEALED		MILL ANNEALED
373 MPY	ASTM G-28A [1]	238 MPY
2752 MPY	ASTM G-28B [2]	49 MPY
1535 MPY	GREEN DEATH [3]	24 MPY
PITTING		NO ATTACK

ASTM G-28B   GREEN-DEATH



ASTM G-28B   GREEN DEATH

[1] ASTM G-28A = 50% H_2SO_4 + 42g/l $Fe_2(SO_4)_3$ (Boiling)
[2] ASTM G-28B = 23% H_2SO_4 + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$ (Boiling)
[3] GREEN DEATH = 11.5% H SO + 1.2% HCl + 1% Fe Cl + 1% CuCl (Boiling)24232

When the alloy isspecified by the UNS Number, discerning questions should be asked for assurance of LION C-276 alloy performance:

- Does the product possess the clean, homogeneous microstructure so important for good resistance to aqueous corrosion?
- How does the product perform in tough environments (e.g., rigorous pitting conditions) for which this material is most often specified?
- Is the corrosion resistance of the welded product, in a discriminating test, up to par?

PRINCIPAL FEATURES

Excellent Resistance to Corrosion

LION® C-276 alloy isa nickel-molybdenum-chromium wrought alloy that is generally considered a versatile corrosion-resistant alloy. C-276 alloy is an improved wrought version of alloy C in that it usually doesn't need to be solution heat-treated after welding and has vastly improved fabricability. This alloy resists the formation of grain-boundary precipitates in the weld heat-affected zone, thus making it suitable for most chemical process applications in the as-welded condition. However, in environments where attack of the C-276 alloyweld joint is experienced, C-22® weld filler materials should be considered (See page 14).

C-276 alloyhas excellent resistance to localized corrosion and to both oxidizing and reducing media. Because of its versatility, C -276 alloycan be used where "upset" conditions are likely to occur or in multipurpose plants.

LION C-276 alloyhas excellent resistance to a wide variety of chemical process environments, including strong oxidizers such as ferric and cupric chlorides, hot contaminated media (organic and inorganic), chlorine, formic and acetic acids, acetic anhydride, and seawater and brine solutions. It is used in flue gas desulfurization systems because of its excellent resistance to sulfur compounds and chloride ions encountered in most scrubbers. C-276 alloyhas excellent resistance to pitting and to stress-corrosion cracking. It is also one of the few materials that withstands the corrosive effects of wet chlorine gas, hypochlorite and chlorine dioxide.

Fabricated by a Variety of Methods

LION C-276 alloycan be forged, hot-upset and impact extruded. Although the alloy tends to work-harden, it can be successfully deep-drawn, spun, press formed or punched. All of the common methods of welding can be used to weld LION C-276 alloy, although the oxyacetylene and submerged arc processes are not recommended when the fabricated item is intended for use in corrosion service. Special precautions should be taken to avoid excessive heat in-put.

Detailed fabricating information is available in the booklet, "Fabrication of LION® Corrosion-Resistant Alloys." Ask for booklet H-2010.

Available in Wrought Form

LION C-276 alloy is available in the form of plate, sheet, strip, billet, bar, wire, covered electrodes, pipe, tubing, pipe fittings, flanges and fittings.

Heat-Treatment

Wrought forms of LION-C 276 alloy are furnished in the solution heat-treated condition unless otherwise specified. C-276 alloy isnormally solution heat-treated at 2050 °F (1121 °C) and rapid quenched. Parts which have been hot-formed should be solution heat-treated prior to final fabrication or installation, if possible.

ASME Boiler and Pressure Vessel Code

LION C-276 alloyplate, sheet, strip, bar, tubing and pipe are covered by ASME specifications SB-574, SB-575, SB-619, SB-622 and SB-626 under UNS number N10276.

NOMINAL CHEMICAL COMPOSITION, (CONSISTS OF ABOUT) WEIGHT PERCENT*

Ni	Co	Cr	Mo	W	Fe	Si	Mn	C	Others
57	2.5**	14.5-16.5	15.0-17.0	3.0-4.5	4.0-7.0	0.08**	1.0**	0.01**	V-0.35** P-0.025 S-0.010**

*The undiluted deposited chemical composition of alloy C-276 covered electrodes has 0.02 percent maximum carbon,0.20 percent maximum silicon,0.03 percent maximum phosphorus and 0.015 percent maximum sulfur.
**Maximum

AVERAGE PHYSICAL PROPERTIES

Physical Property	Temperature, °F	British Units	Temperature, °C	Metric Units
Density	72	0.321 lb./in^3	22	8.89 g/cm^3
Melting Range	2415-2500		1323-1371	
Electrical Resistivity	75	51 microhm-in.	24	1.30 microhm-m
Mean Coefficient of Thermal Expansion	75-200	6.2 microinches/in.- °F	24-93	11.2 x 10^{-6}m/m•K
	75-400	6.7 microinches/in.- °F	24-204	12.0 x 10^{-6}m/m•K
	75-600	7.1 microinches/in.- °F	24-316	12.8 x 10^{-6}m/m•K
	75-800	7.3 microinches/in.- °F	24-427	13.2 x 10^{-6}m/m•K
	75-1000	7.4 microinches/in.- °F	24-538	13.4 x 10^{-6}m/m•K
Thermal Conductivity	-270	50 Btu-in./ft.^{2}-hr.- °F	-168	7.2 W/m•K
	-100	60 Btu-in./ft.^{2}-hr.- °F	-73	8.6 W/m•K
	0	65 Btu-in./ft.^{2}-hr.- °F	-18	9.4 W/m•K
	100	71 Btu-in./ft.^{2}-hr.- °F	38	10.2 W/m•K
	200	77 Btu-in./ft.^{2}-hr.- °F	93	11.1 W/m•K
	400	90 Btu-in./ft.^{2}-hr.- °F	204	13.0 W/m•K
	600	104 Btu-in./ft.^{2}-hr.- °F	316	15.0 W/m•K
	800	117 Btu-in./ft.^{2}-hr.- °F	427	16.9 W/m•K
	1000	132 Btu-in./ft.^{2}-hr.- °F	538	19.0 W/m•K
Specific Heat (Calculated)	Room	0.102 Btu/lb.- °F	Room	427 J/Kg•K

AVERAGE DYNAMIC MODULUS OF ELASTICITY

Form	Condition	Test Temperatures °F (°C)	Average Dynamic Modulus of Elasticity, 10^6 psi (GPa)
Plate	Heat-treated at 2050 °F (1121 °C), Rapid Quenched	Room	29.8 (205)
		400 (204)	28.3 (195)
		600 (316)	27.3 (188)
		800 (427)	26.4 (182)
		1000 (538)	25.5 (176)

FORMABILITY

Form	Condition	Average Olsen Cup Depth in.	mm
Sheet, 0.044 in. (1.1mm) thick	Heat-treated at 2050 °F (1121 °C), Rapid Quenched	0.48*	12.2*

*Average of six tests.

AVERAGE IMPACT STRENGTH, PLATE

Condition	"U" Notch Impact Strength at –320 °F(–196 °C) ft.-lb.	J
Solution Heat-Treated at: 2050 °F (1121 °C), Rapid Quenched	263*	357
Aged 100 hrs. at: 500 °F (260 °C)	250	339
1000 °F (538 °C)	96	130
Aged 1000 hrs. at: 1000 °F (538 °C)	64	87

*Five of six specimens did not break.

Cryogenic Notch Toughness

This "U" notch specimen of alloy C-276 did not break under the hammer blow of the impact tester at -320 °F (-196 °C).

AVERAGE TENSILE DATA, SOLUTION HEAT-TREATED

Form	Test Temperature °F(°C)	Ultimate Tensile Strength Ksi*	Yield Strength at 0.2% offset, Ksi*	Elongation in 2 in. (50.8mm) %
Sheet 0.078 iin. (2.0mm) thick	Room	114.9	51.6	61
	400 (204)	100.6	42.0	59
	600 (316)	98.8	35.9	68
	800 (427)	94.3	32.7	67
Sheet, 0.094 in. (2.4mm) thick	400 (204)	101.0	39.9	58
	600 (316)	97.6	33.5	64
	800 (427)	93.5	29.7	64
Sheet, 0.063 to 0.187 in. (1.6 to 4.7mm) thick	400 (204) [1]	100.8	42.1	56
	600 (316) [2]	97.0	37.7	64
	800 (427) [2]	95.0	34.8	65
	1000 (538) [2]	88.9	33.8	60
Plate, 3/16 to 1 in. (4.8 to 25.4mm) thick	400 (204) [3]	98.9	38.2	61
	600 (316) [3]	94.3	34.1	66
	800 (427) [3]	91.5	32.7	60
	1000 (538) [3]	87.2	32.8	59
Plate, 1 in. (25.4mm) thick	Room	113.9	52.9	59
	600 (316)	96.3	36.2	63
	800 (427)	94.8	30.5	61

*Ksi can be converted to MPa (megapascals) by multiplying by 6.895.

1-Average of 25 tests.
2-Average of 34-36 tests.
3-Average of 9-11 tests.

AVERAGE ROOM TEMPERATURE HARDNESS

Form	Hardness, Rockwell
Sheet**	Rb 90
Plate***	Rb 87

**Average of 49 tests.
***Average of 35 tests.

COMPARATIVE AQUEOUS CORROSION DATA

Media	Concentration, percent by weight	Test Temp., °F (°C)	Average Corrosion Rate per year, mils*			
			C-276 alloy	C-22® alloy	C-4 alloy	625 alloy
Acetic Acid	99	Boiling	<1	Nil	Nil	<1
Ferric Chloride	10	Boiling	2	1	140	7689
Formic Acid	88	Boiling	2	<1	3	9
Hydrochloric Acid	1	Boiling	10	3	36	1
	1.5	Boiling	29	11	64	353
	2	194 (90)	1	Nil	31	Nil
	2	Boiling	51	61	85	557
	3	194 (90)	12	<1	34	72
	3	Boiling	70	84	44	296
	10	Boiling	288	400	228	642
Hydrochloric Acid + 42 g/l $Fe_2(SO_4)_3$	1	200 (93)	41	2	10	238
	5	150 (66)	5	2	3	2
Hydrochloric Acid + 2% HF	5	158 (70)	26	59	34	123
Hydrofluoric Acid	2	158 (70)	9	9	17	20
	5	158 (70)	10	14	15	16
P_2O_5 (Commercial Grade)	38	185 (85)	9	2	–	1
	44	240 (116)	100	21	–	23
	52	240 (116)	33	11	–	12
P_2O_5 + 2000 ppm Cl	38	185 (85)	12	1	–	2
P_2O_5 + 0.5% HF	38	185 (85)	45	7	–	9
Nitric Acid	10	Boiling	17	<1	14	1
	65	Boiling	888	53	217	20
Nitric Acid + 6% HF	5	140 (60)	207	67	204	73
Nitric Acid + 25% H_2SO_4 + 4% NaCl	5	Boiling	64	12	97	713
Nitric Acid + 1% HCl	5	Boiling	8	<1	11	1
Nitric Acid + 2.5% HCl	5	Boiling	21	2	26	<1
Nitric Acid + 15.8% HCl	9	126 (52)	33	4	114	> 10,000

*To convert mils per year (mpy) to mm per year, divide by 40.

COMPARATIVE AQUEOUS CORROSION DATA CONTINUED

Media	Concen-tration, percent by weight	Test Temp., °F (°C)	Average Corrosion Rate per year, mils*			
			C-276 alloy	C-22® alloy	C-4 alloy	625 alloy
Sulfuric Acid	10	Boiling	23	11	31	46
	20	150 (66)	<1	<1	<1	<1
	20	174 (79)	3	1	2	<1
	20	Boiling	42	33	36	124
	30	150 (66)	<1	1	<1	<1
	30	174 (79)	4	3	3	<1
	30	Boiling	55	64	73	238
	40	100 (38)	<1	<1	<1	<1
	40	150 (66)	1	<1	10	17
	40	174 (79)	10	6	15	35
	50	100 (38)	Nil	<1	<1	1
	50	150 (66)	4	1	13	25
	50	174 (79)	12	16	25	52
	60	100(38)	<1	<1	<1	<1
	70	100 (38)	Nil	Nil	2	<1
	80	100 (38)	<1	Nil	<1	<1
Sulfuric Acid + 0.1% HCl	5	Boiling	42	26	49	151
Sulfuric Acid + 0.5% HCl	5	Boiling	49	61	91	434
Sulfuric Acid + 1% HCl	10	158 (70)	11	<1	24	121
Sulfuric Acid + 1% HCl	10	194 (90)	45	93	66	326
Sulfuric Acid + 1% HCl	10	Boiling	116	225	192	869
Sulfuric Acid + 2% HF	10	Boiling	22	29	26	55
Sulfuric Acid + 200 ppm Cl–	25	158 (70)	12	11	37	110
Sulfuric Acid + 200 ppm Cl–	25	Boiling	186	226	182	325
Sulfuric Acid + 1.2% HCl + 1% $FeCl_3$ + 1% Cu Cl_2	11.5	Boiling	24	3	1020	1664
Sulfuric Acid + 1.2% HCl + 1% $FeCl_3$ + 1% Cu Cl_2 (ASTMG28B)	23	Boiling	55	7	2294	3847
Sulfuric Acid + 42 g/l $Fe_2(SO_4)_3$ (ASTMG28A)	50	Boiling	240	24	167	23

*To convert mils per year (mpy) to mm per year, divide by 40.

CREVICE-CORROSION DATA IN 10% FERRIC CHLORIDE AT ROOM TEMPERATURE FOR 10 DAYS

Alloy	Number of Attacked Crevices*	Maximum Depth of Penetration, mils**
LION® C-276 alloy	0	0
LION® C-22® alloy	0	0
LION® 625 alloy	11	3
Type 317LM Stainless Steel	20	12
Alloy No. 904L	23	19
20Cb-3® alloy	24	76
Alloy 825	24	125

*Maximum possible number of crevices was 24.
**To convert mils per year (mpy) to mm per year, divide by 40.
20Cb-3 is a trademark of Carpenter Technology Corporation.

COMPARATIVE CREVICE-CORROSION TEST DATA IN 10% FERRIC CHLORIDE

Alloy	Average Corrosion Rate, mils per year*		
	77 °F (25 °C)	122 °F (50 °C)	167 °F (75 °C)
LION C-276 alloy	0.2	0.2	1.4
LIONC-22 alloy	0.1	0.1	0.5
LIONC-4 alloy	0.3	0.5	20
LION255 alloy	0.4	811	663
LION625 alloy	1.5	124	510
20Cb-3 alloy	205	380	700
Type 316L Stainless Steel	312	460	780
Alloy 825	730	707	680

*Average corrosion rate on duplicate samples even though most corrosion occurred under crevice. Tests were for 100 hours with grooved block.
To convert mils per year (mpy) to mm per year, divide by 40.

COMPARATIVE STRESS-CORROSION CRACKING DATA

Alloy	Time,hrs. to crack in 45% Magnesium Chloride at 309 °F (154 °C)
Type 304 Stainless Steel	1-2
Type 316L Stainless Steel	1-2
20Cb-3 alloy	22
Alloy 825	46
LION625 alloy	No cracks - 1000
LIONG-30 alloy	No cracks - 1000
LION C-276 alloy	No cracks - 1000
LIONC-22 alloy	No cracks - 1000

COMPARATIVE IMMERSION CRITICAL PITTING AND CRITICAL CREVICE-CORROSION TEMPERATURES IN OXIDIZING NaCl-HCl SOLUTION

The chemical composition of the solution used in this test is as follows: 4% NaCl + 0.1% $Fe_2(SO_4)_3$ + 0.021 M HCl. This solution contains 24,300 ppm chlorides and is acidic (pH2).

In both pitting and crevice-corrosion testing the solution temperature was varied in 5 °C increments to determine the lowest temperature at which pitting-corrosion initiated (observed by examination at a magnification of 40X of duplicate samples) after a 24-hour exposure period (Pitting Temperature), and the lowest temperature at which crevice-corrosion initiated in a 100-hour exposure period (Crevice-Corrosion Temperature).

Alloy	Critical Pitting Temperature °C	°F	Critical Crevice-Corrosion Temperature °C	°F
LION® C-22® alloy	> 150	> 302	102	212 (Boiling)
LION C-276 alloy	150	302	80	176
LIONC-4 alloy	140	284	50	122
LION®625 alloy	90	194	50	122
LIONG-30® alloy	75	167	–	–
LION'® 255 alloy	50	122	35	95
Alloy 904L	45	113	20	68
Type 317LM Stainless Steel	35	95	15	59
Type 317L Stainless Steel	25	77	10	50
Alloy 825	25	77	δ-5	δ 23
20Cb-3® alloy	25	68	δ-5	δ23
Type 316 Stainless Steel	20	68	δ-5	δ23

20Cb-3 is a trademark of Carpenter Technology Corporation.

COMPARATIVE IMMERSION CREVICE-CORROSION TEMPERATURES IN 6% FERRIC CHLORIDE SOLUTION (ASTM G48; MTI Project)

The chemical composition of the solution used in this test is as follows: 6% Fe_2Cl_3 . In the crevice-corrosion test, the solution temperature was varied in 2.5 °C increments to determine the lowest temperature at which crevice corrosion initiated in a 24-hour exposure period (Crevice-Corrosion Temperature).

Alloy	Crevice-Corrosion Temperature °C	°F
LIONC-22 alloy	> 100	> 212
LION'C-276 alloy	95	203
LIONC-4 alloy	42.5	109
LION625 alloy	40	104
LIONG-30 alloy	30	86
Nickel 200	30	86
LION255 alloy	45	113
Alloy 904L	5	41
Type 317 Stainless Steel	2.5	37

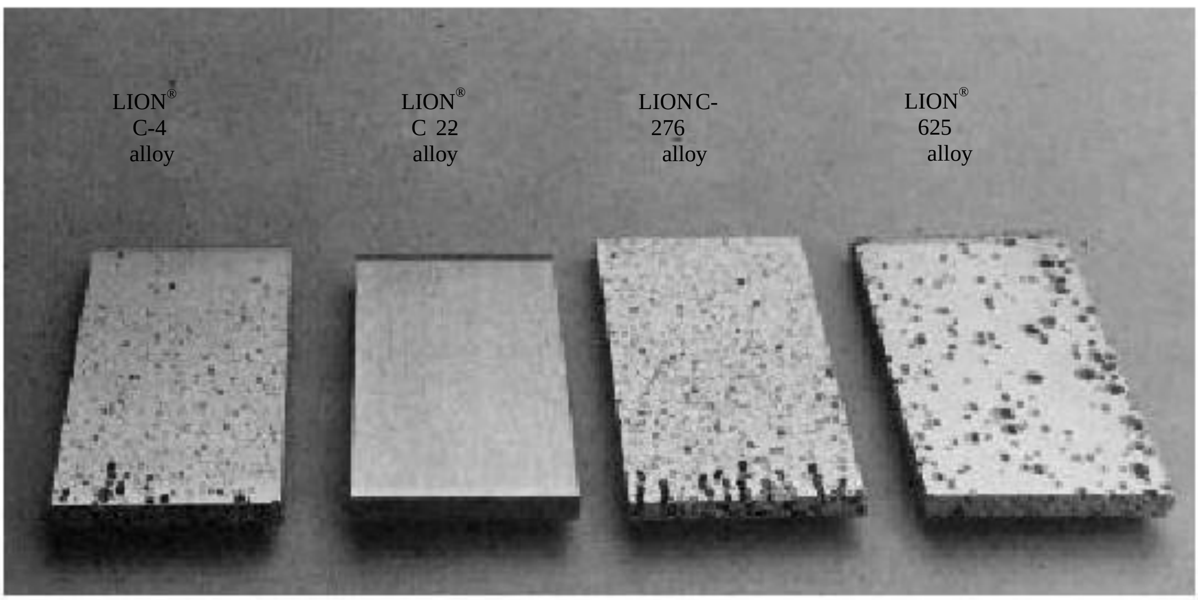
COMPARATIVE CRITICAL PITTING TEMPERATURES IN OXIDIZING H_2SO_4-HCl SOLUTION

The chemical composition of the solution used in this test is as follows: 11.5% H_2SO_4 + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$. This test environment is a severely oxidizing acid solution which is used to evaluate the resistance of alloys to localized corrosion. It is considerably more aggressive than the oxidizing NaCl-HCl test. Experiments were performed in increments of solution temperature of 5 deg. C for a 24-hour exposure period to determine the critical pitting temperature, i.e. the lowest temperature at which pitting corrosion initiated (observed at a magnification of 40X of duplicate samples.)

Alloy	Critical Pitting Temperature ℃	℉
LION® C-22® alloy	120	248
LION C-276 alloy	110	230
LIONC-4 alloy	90	194
LION® 625 alloy	75	167

LIONALLOYS EXCEL IN PITTING RESISTANCE

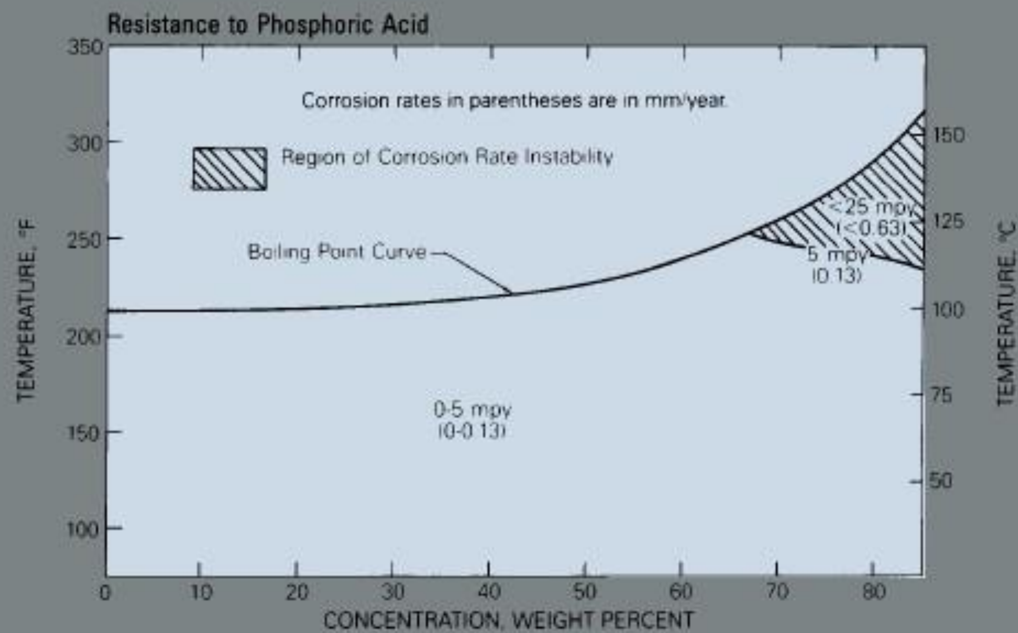
As a class, C-type alloys excel in pitting corrosion resistance. However, comparison tests in a severe pitting environment show LIONC-22 alloy to be in a class by itself.



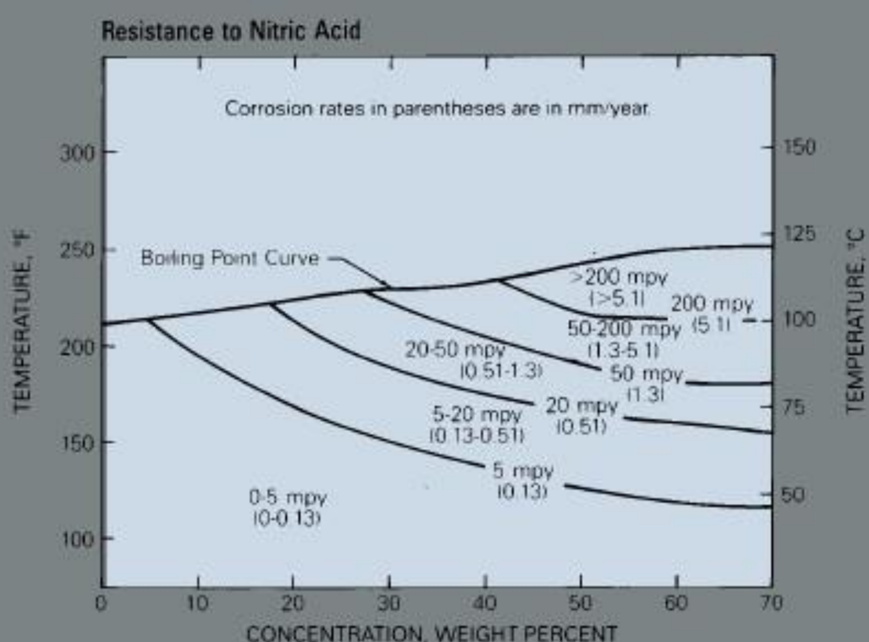
Samples were subjected to a solution of 11.5% H_2SO_4 + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$.
Solutions for coupons 625 and C-4 were at 102 ℃, while C-276 and C-22 were at 125 ℃.

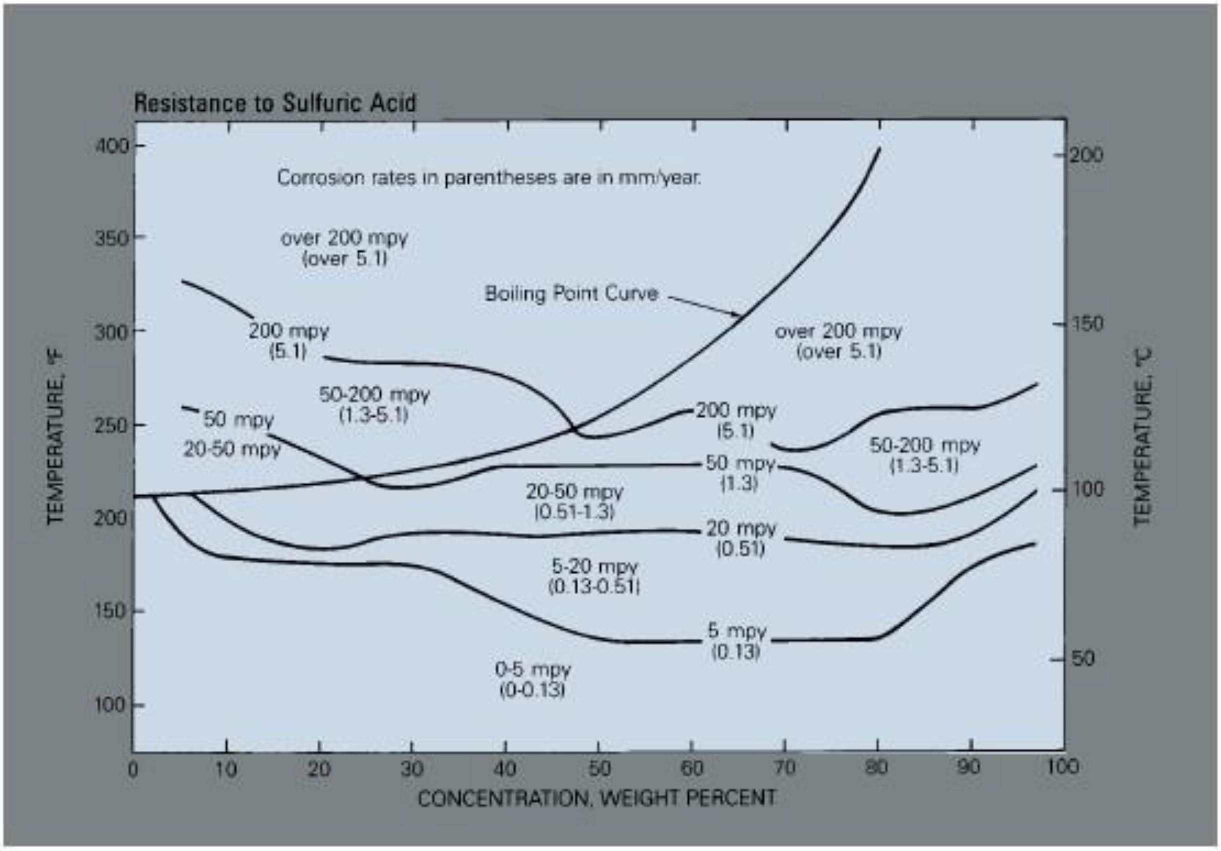
ISOCORROSION DIAGRAMS

The isocorrosion diagrams shown on this and subsequent pages were plotted using data obtained in laboratory tests in reagent grade acids. These data should be used only as a guide. It is recommended that samples be tested under actual plant conditions.

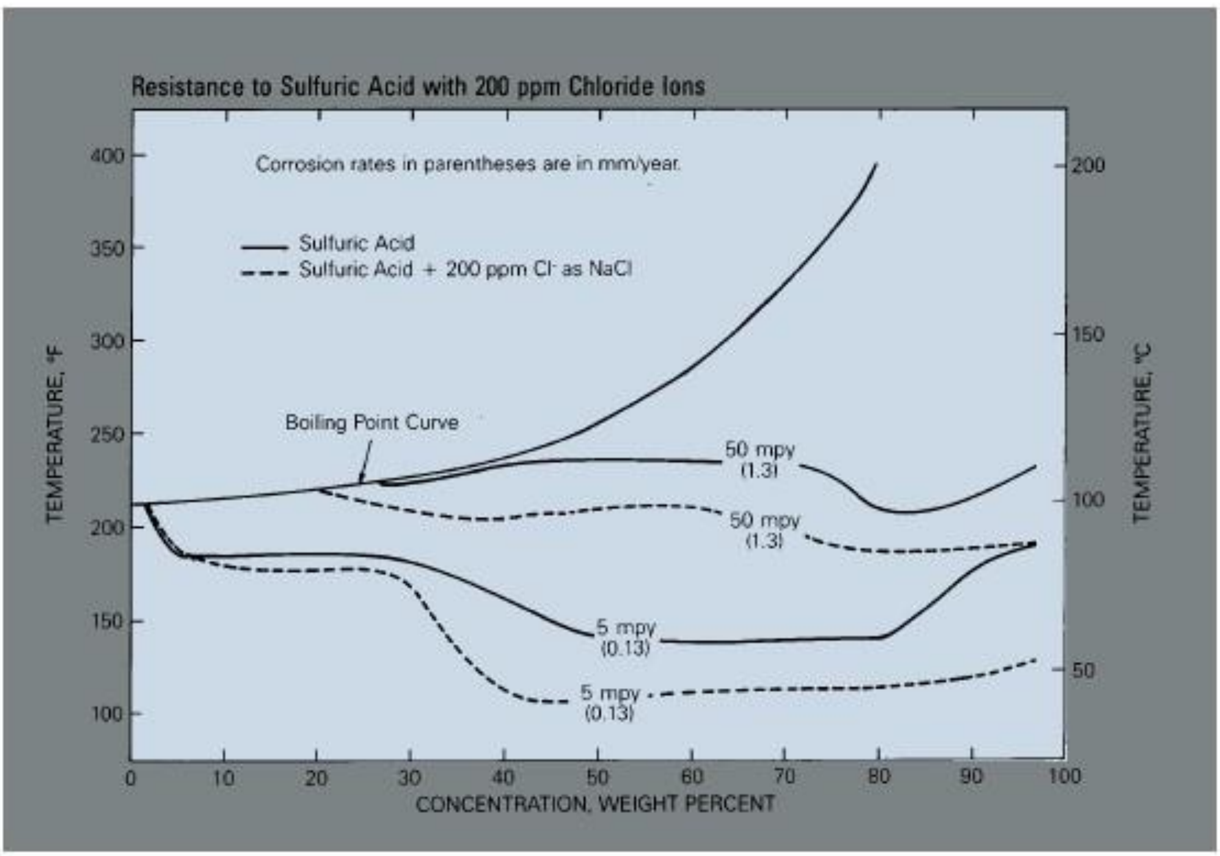


*All test specimens were heat-treated at 2050 ℉ (1121 ℃),rapid quenched and in the unwelded condition.

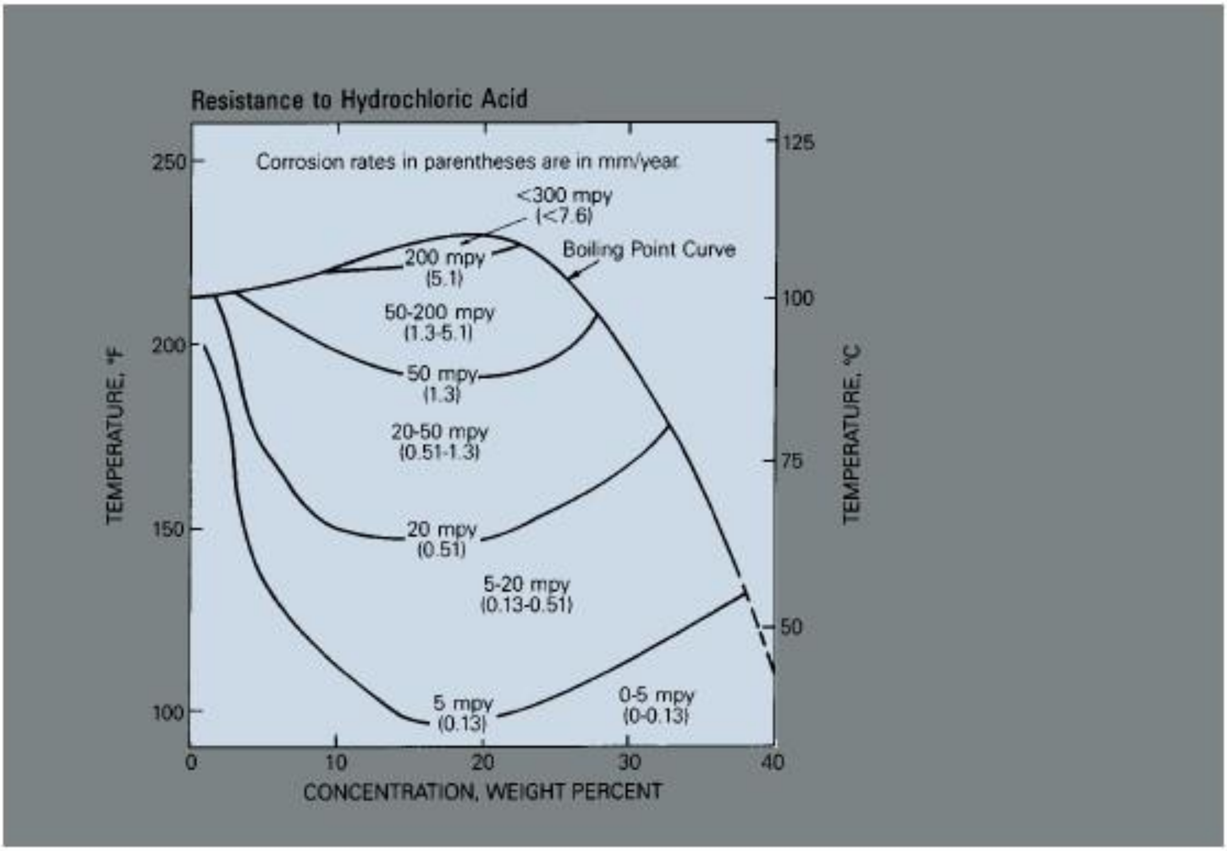


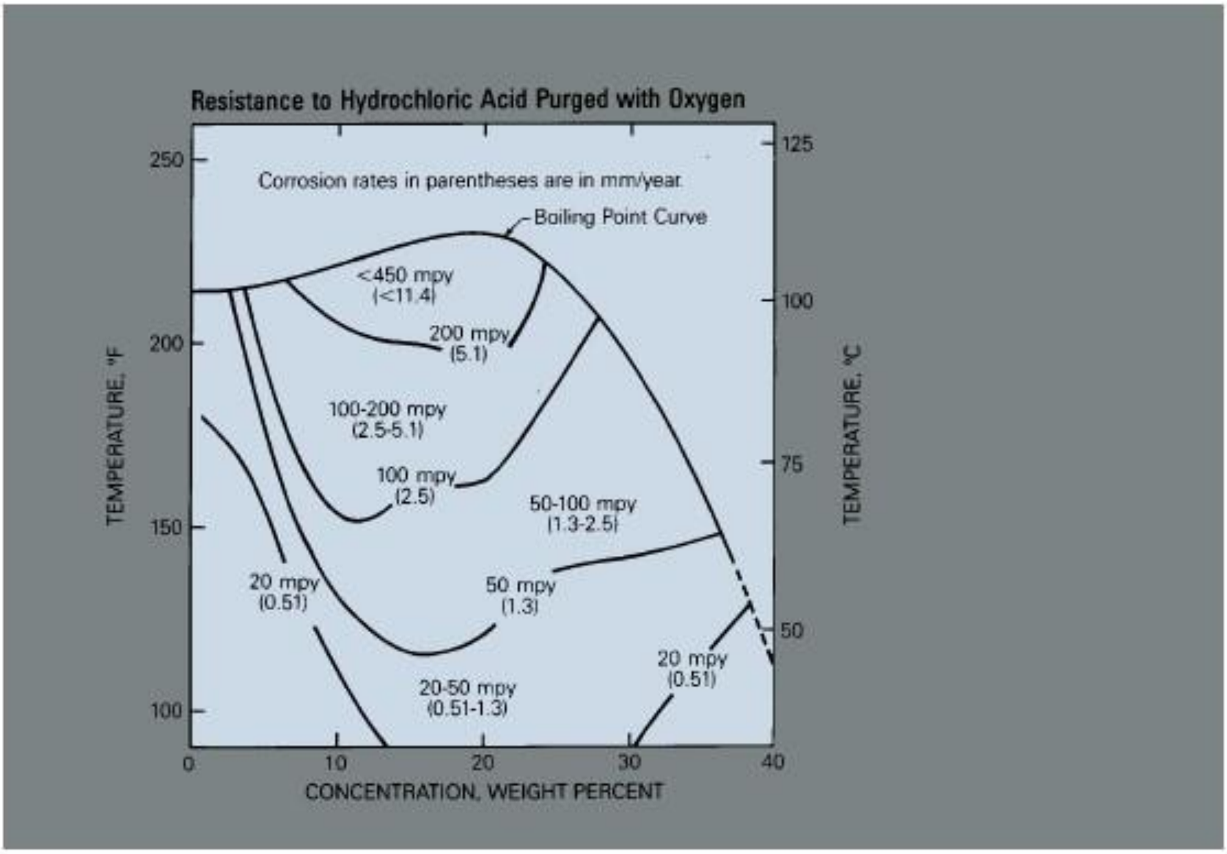


Resistance to Sulfuric Acid
Corrosion rates in parentheses are in mm/year.
over 200 mpy
(over 5.1)
Boiling Point Curve
200 mpy
(5.1)
over 200 mpy
(over 5.1)
50-200 mpy
(1.3-5.1)
50 mpy
20-50 mpy
200 mpy
(5.1)
50-200 mpy
(1.3-5.1)
50 mpy
(1.3)
20-50 mpy
(0.51-1.3)
20 mpy
(0.51)
5-20 mpy
(0.13-0.51)
5 mpy
(0.13)
0-5 mpy
(0-0.13)
TEMPERATURE, °F
TEMPERATURE, °C
CONCENTRATION, WEIGHT PERCENT

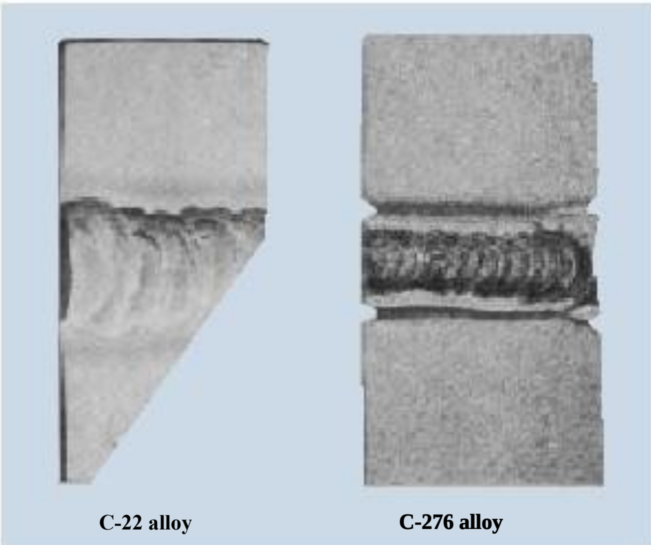


Resistance to Sulfuric Acid with 200 ppm Chloride Ions
Corrosion rates in parentheses are in mm/year.
Sulfuric Acid
Sulfuric Acid + 200 ppm Cl- as NaCl
Boiling Point Curve
50 mpy
(1.3)
50 mpy
(1.3)
5 mpy
(0.13)
5 mpy
(0.13)
TEMPERATURE, °F
TEMPERATURE, °C
CONCENTRATION, WEIGHT PERCENT


Resistance to Hydrochloric Acid
Corrosion rates in parentheses are in mm/year.
<300 mpy
(<7.6)
Boiling Point Curve
200 mpy
(5.1)
50-200 mpy
(1.3-5.1)
50 mpy
(1.3)
20-50 mpy
(0.51-1.3)
20 mpy
(0.51)
5-20 mpy
(0.13-0.51)
5 mpy
(0.13)
0-5 mpy
(0-0.13)
TEMPERATURE, °F
TEMPERATURE, °C
CONCENTRATION, WEIGHT PERCENT


Resistance to Hydrochloric Acid Purged with Oxygen
Corrosion rates in parentheses are in mm/year.
Boiling Point Curve
<450 mpy
(<11.4)
200 mpy
(5.1)
100-200 mpy
(2.5-5.1)
100 mpy
(2.5)
50-100 mpy
(1.3-2.5)
20 mpy
(0.51)
50 mpy
(1.3)
20 mpy
(0.51)
20-50 mpy
(0.51-1.3)
TEMPERATURE, °F
TEMPERATURE, °C
CONCENTRATION, WEIGHT PERCENT

Improved Corrosion Resistance of LION® C-22® Weldments



Corrosion behavior of welded samples showing the improved performance of C-22 alloy over that of C-276 alloy.

Weld overlays of LIONC-22 alloy, used to protect C-276 alloyweldments, can be seen on bleach plant mixer.