HAYNES International

HASTELLOY® C-4 Alloy

HASTELLOY C-4 alloy is a nickel-chromium-molybdenum alloy with outstanding high-temperature stability as evidenced by high ductility and corrosion resistance even after aging in the 1200 to 1900°F (649 to 1038°C) range. 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. C-4 alloy also has excellent resistance to stress-corrosion cracking and to oxidizing atmospheres up to 1900°F (1038°C).

HASTELLOY C-4 alloy has exceptional resistance to wide variety of chemical process environments. These include hot contaminated mineral acids, solvents, chlorine and chlorine contaminated media (organic and inorganic), dry chlorine, formic and acetic acids, acetic anhydride, and seawater and brine solutions.

Laboratory precipitation studies on C-4 alloy indicate that the intermetallic precipitates (Mu phase) associated with other nickel alloys in the 1200 to 2000°F (649 to 1093°C) temperature range have not been detected. Fine intergranular M_6C carbides can form but their damaging effect is minimal.

HASTELLOY C-4 alloy can 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 HASTELLOY C-4 alloy, although the oxy-acetylene 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 input.

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

Wrought forms of HASTELLOY C-4 alloy are furnished in the solution heat-treated condition unless otherwise specified. C-4 alloy is solution heat-treated at 1950°F (1066°C) and rapid quenched.

HASTELLOY C-4 alloy plate, sheet, strip, bar, tubing and pipe are covered by ASME specifications SB-574, SB-575, SB-6119, SB-622 and SB-626 under UNS number N06455.

Nominal Chemical Composition, Weight Percent*

Ni	Co	Cr	Mo	Ti	Fe	Si	Mn	C	Others
65[a]	2.0**	14.0-18.0	14.0-17.0	0.70**	3.0**	0.08**	1.0**	0.01**	P-0.025** S-0.010**

*The undiluted deposited chemical composition of C-4 alloy covered electrodes has 0.015 percent maximum carbon, 0.20 percent maximum silicon and 1.5 percent maximum manganese.
**Maximum
[a]As balance

TYPICAL PHYSICAL PROPERTIES

Physical Property	Temp., °F	British Units	Temp., °C	Metric Units
Density	68	0.312 lb/in.^{3}	20	8.64 g/cm.^{3}
Electrical Resistivity	74	49.1 microhm-in.	23	1.25 microhm-m
	77	44.1[a] microhm-in.	25	1.12[a] microhm-m
	212	49.3 microhm-in.	100	1.25 microhm-m
	392	49.6 microhm-in.	200	1.26 microhm-m
	572	49.9 microhm-in.	300	1.27 microhm-m
	752	50.2 microhm-in.	400	1.28 microhm-m
	932	50.8 microhm-in.	500	1.29 microhm-m
	1112	51.8 microhm-in.	600	1.32 microhm-m
Mean Coefficient of	68-200	6.0 microinches/in.-°F	20-93	10.8 x 10^{-6} m/m-K
Thermal Expansion	68-400	6.6 microinches/in.-°F	20-204	11.9 x 10^{-6} m/m-K
	68-600	7.0 microinches/in.-°F	20-316	12.6 x 10^{-6} m/m-K
	68-800	7.2 microinches/in.-°F	20-427	13.0 x 10^{-6} m/m-K
	68-1000	7.4 microinches/in.-°F	20-538	13.3 x 10^{-6} m/m-K
	68-1200	7.5 microinches/in.-°F	20-649	13.5 x 10^{-6} m/m-K
	68-1400	8.0 microinches/in.-°F	20-760	14.4 x 10^{-6} m/m-K
	68-1600	8.3 microinches/in.-°F	20-871	14.9 x 10^{-6} m/m-K
	68-1800	8.7 microinches/in.-°F	25-982	15.7 x 10^{-6} m/m-K
Thermal Conductivity	74	70 Btu-in./ft.^{2} hr.-°F	23	10.1 W/m-K
	212	79 Btu-in./ft.^{2} hr.-°F	100	11.4 W/m-K
	392	92 Btu-in./ft.^{2} hr.-°F	200	13.2 W/m-K
	572	104 Btu-in./ft.^{2} hr.-°F	300	15.0 W/m-K
	752	116 Btu-in./ft.^{2} hr.-°F	400	16.7 W/m-K
	932	128 Btu-in./ft.^{2} hr.-°F	500	18.4 W/m-K
	1112	142 Btu-in./ft.^{2} hr.-°F	600	20.5 W/m-K
Specific Heat	32	0.097 Btu/lb.-°F	0	406 J/kg-K
	212	0.102 Btu/lb.-°F	100	427 J/kg-K
	392	0.107 Btu/lb.-°F	200	448 J/kg-K
	572	0.111 Btu/lb.-°F	300	465 J/kg-K
	752	0.114 Btu/lb.-°F	400	477 J/kg-K
	932	0.117 Btu/lb.-°F	500	490 J/kg-K
	1112	0.120 Btu/lb.-°F	600	502 J/kg-K
Thermal Diffusivity	74	0.004 in.^{2}/sec.	23	2.8 x 10^{-6} m^2/s
	212	0.005 in.^{2}/sec.	100	3.1 x 10^{-6} m^2/s
	392	0.005 in.^{2}/sec.	200	3.3 x 10^{-6} m^2/s
	572	0.006 in.^{2}/sec.	300	3.7 x 10^{-6} m^2/s
	752	0.006 in.^{2}/sec.	400	4.0 x 10^{-6} m^2/s
	932	0.007 in.^{2}/sec.	500	4.3 x 10^{-6} m^2/s
	1112	0.007 in.^{2}/sec.	600	4.7 x 10^{-6} m^2/s

a - specimens aged 16,000 hours at 1200°F (659°C.)

AVERAGE DYNAMIC MODULUS OF ELASTICITY*

Form	Condition	Test Temperature °F	Test Temperature °C	Modulus of Elasticity 10^6 psi	Modulus of Elasticity GPa
Plate, 1/2 in.	Heat-treated at	Room	Room	30.8	211
(12.7 mm) thick	at 1950°F(1066°C)	200	93	30.2	207
	rapid quench	400	204	29.3	201
		600	316	28.3	194
		800	427	27.3	187
		1000	538	26.2	179
		1200	649	25.0	171
		1400	760	23.7	162
		1600	871	22.2	152
		1800	982	20.6	141

*Average of three tests at each temperature.

AVERAGE FORMABILITY

Form	Condition	Average Olsen Cup Depth,* in.	Average Olsen Cup Depth,* mm
Sheet, 0.065 in. (1.7 mm) thick	Heat-treated at at 1950°F (1066°C), rapid quench	0.52	13.2
	Aged 1000 hours at 1600°F (871°C)	0.52	13.2

*Average of five tests.

AVERAGE OXIDATION DATA

Test Temperature °F	Test Temperature °C	Average Oxidation Rate per 100-hour test period - 100 hours, intermittent* mils	Average Oxidation Rate per 100-hour test period - 100 hours, intermittent* mm
1900	1038	0.16	0.004

*Four 25-hour periods. Cycled to room temperature after each period.

AVERAGE HARDNESS AND TENSILE DATA, SHEET

Form	Condition	Test Temp. °F	Test Temp. °C	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	Yield Strength at 0.2% Offset Ksi	Yield Strength at 0.2% Offset MPa	Elongation in 2 in (51mm) %	Hardness Rockwell
Sheet, 0.065 in.	Heat-treated at	Room	Room	111.4	768	60.3	416	52	B-90
(1.7 mm) thick	at 1950°F(1066°C)	400	204	102.4	706	58.5	403	49	-
	rapid quench	600	316	97.9	675	53.8	371	52	-
		800	427	95.2	656	46.4	320	64	-
Sheet, 0.125 in.	Heat-treated at	Room	Room	116.2	801	61.0	421	54	B-92
(3.2 mm) thick	at 1950°F(1066°C)	400	204	98.3	678	46.4	320	54	-
	rapid quench	600	316	97.5	672	43.9	303	59	-
		800	427	93.4	644	43.9	303	62	-
		1000	538	93.5	645	43.4	299	55	-
		1200	649	82.8	571	42.2	291	50	-
		1400	760	69.0	476	37.7	260	44	-
Sheet, 0.156 in.	Heat-treated at	Room	Room	113.5	783	53.0	365	55	B-91
(4.0 mm) thick	at 1950°F(1066°C)	400	204	99.9	689	39.9	275	55	-
	rapid quench	600	316	95.3	657	36.1	249	61	-
		800	427	95.1	656	36.2	250	68	-

AVERAGE TENSILE DATA, AGED SHEET AND PLATE

Form	Condition	Test Temp. °F	Test Temp. °C	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	Yield Strength at 0.2% Offset Ksi	Yield Strength at 0.2% Offset MPa	Elongation in 2 in (51mm) %
Sheet, 0.125 in.	Aged 100 hrs.	Room	Room	114.6	790	54.6	376	56
(3.2 mm) thick	at 1650°F(899°C)	400	204	103.2	712	47.1	325	54
		600	316	99.5	686	43.1	297	57
		800	427	97.0	669	40.6	280	60
		1000	538	93.3	643	39.9	275	57
		1200	649	86.6	597	37.2	256	56
		1400	760	76.2	525	36.3	250	56
Plate, 3/8 in.	Aged 100 hrs.	Room	Room	111.8	771	48.7	336	62
(9.5 mm) thick	at 1650°F(899°C)	400	204	100.6	694	39.5	272	51
		600	316	98.0	676	37.0	255	56
		800	427	97.2	670	37.1	256	57
		1000	538	89.6	618	32.1	221	53
		1200	649	89.6	618	34.1	235	56
		1400	760	73.5	507	29.7	205	70

AVERAGE TENSILE DATA, PLATE AND WELDMENTS

Form	Condition	Test Temp. °F	Test Temp. °C	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	Yield Strength at 0.2% Offset Ksi	Yield Strength at 0.2% Offset MPa	Elongation in 2 in (51mm) %
Plate, 1/4 in.	Heat-treated at	Room	Room	111.3	767	48.8	336	58
(6.3 mm) thick	1950°F(1066°C)	400	204	104.0	717	42.8	295	54
	rapid quenched	600	316	103.3	712	40.8	281	55
		800	427	99.0	683	37.0	255	60
Plate, 3/8 in.	Heat-treated at	Room	Room	114.7	791	51.6	356	59
(9.5 mm) thick	1950°F(1066°C)	400	204	105.4	727	43.6	301	56
	rapid quenched	600	316	102.1	704	39.1	270	59
		800	427	96.3	657	37.4	258	62
		1000	538	93.3	643	33.0	228	52
		1200	649	84.7	584	31.5	217	52
		1400	760	70.0	483	30.6	211	63
Plate, 1/2 in.	Heat-treated at	Room	Room	116.8	805	48.6	335	63
(12.7 mm) thick	1950°F(1066°C)	200	93	110.9	765	43.7	301	70
	rapid quenched	400	204	105.2	725	38.3	264	61
		600	316	102.5	707	35.8	247	65
		800	427	99.8	688	34.2	236	66
		1000	538	92.1	635	29.8	205	71
Welded Plate,	As-welded*	Room	Room	112.7	777	68.3	471	40
1/2 in.		500	260	94.9	654	51.0	352	39
(12.7mm) thick		1000	538	87.3	602	48.7	336	35
Welded Plate,	Aged at 1200°F							
1/2 in.	(649°C) for:							
(12.7mm) thick	10 hours	Room	Room	113.7	784	62.2	429	48
	1000 hours	Room	Room	118.7	818	59.6	411	46
All-Weld Metal	As-welded*	Room	Room	107.1	738	71.4	492	42

*As gas tungsten arc welded.

AVERAGE CORROSION DATA*

Media	Concentration, percent by weight	Temp., °F	Temp., °C	Average Corrosion Rate, mils (mm) per year Unwelded** mils	Unwelded** mm	As-welded*** mils	As-welded*** mm	Aged**** mils	Aged**** mm
Formic Acid	20	Boiling		2.9	0.07	3.5	0.09	3.5	0.09
Hydrochloric Acid	10	167	75	36.0	0.91	34.0	0.86	35.0	0.89
Nitric Acid	10	Boiling		5.9	0.15	7.1	0.18	9.2	0.23
Phosphoric Acid	85	Boiling		61.0	1.5	52.0	1.30	85.0	2.20
Sulfuric Acid	10	Boiling		22.0	0.56	25.0	0.64	20.0	0.51
Sulfuric Acid	85	167	75	23.0	0.58	17.0	0.43	21.0	0.53

*Determined in Laboratory tests. It is recommended that samples be tested under actual plant conditions.
** Heat-treated at 1959°F (1066°C), water quenched.
*** Gas tungsten arc welded.
**** Aged 100 hours at 1650°F (899°C)

ACCELERATED QUALITY CONTROL CORROSION TESTS

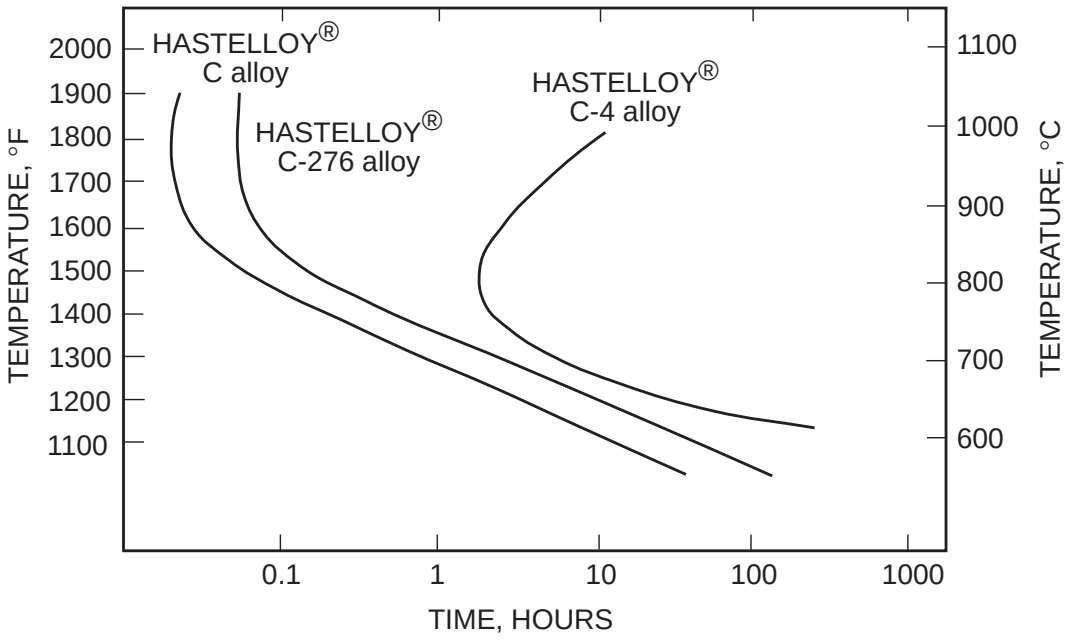
Accelerated tests may be used to assess the overall corrosion resistance of C-4 alloy. Such tests are conducted in an aggressive environment which is considerably more severe than that usually encountered in industrial processes.

Ferric Sulfate Test-Specimens are tested for one 24-hour period in accordance with ASTM G-28A (boiling 50 percent sulfuric acid with 42 grams per liter of ferric sulfate). The presence of grain boundary precipitates results in an accelerated corrosion attack. Typical corrosion rates for C-4 alloy are shown in the following table.

	Average Corrosion Rate, per year					
	Unwelded*		As-welded**		Aged***	
Type of Test	mils	mm	mils	mm	mils	mm
ASTM G-28A	100	2.5	111	2.8	114	2.9

* Solution heat-treated
** Gas tungsten arc welded.
*** Aged 100 hours at 1650°F (899°C)

Relationship of Time and Temperature to Beginning of Precipitate in Ni-Mo-Cr Corrosion Alloys



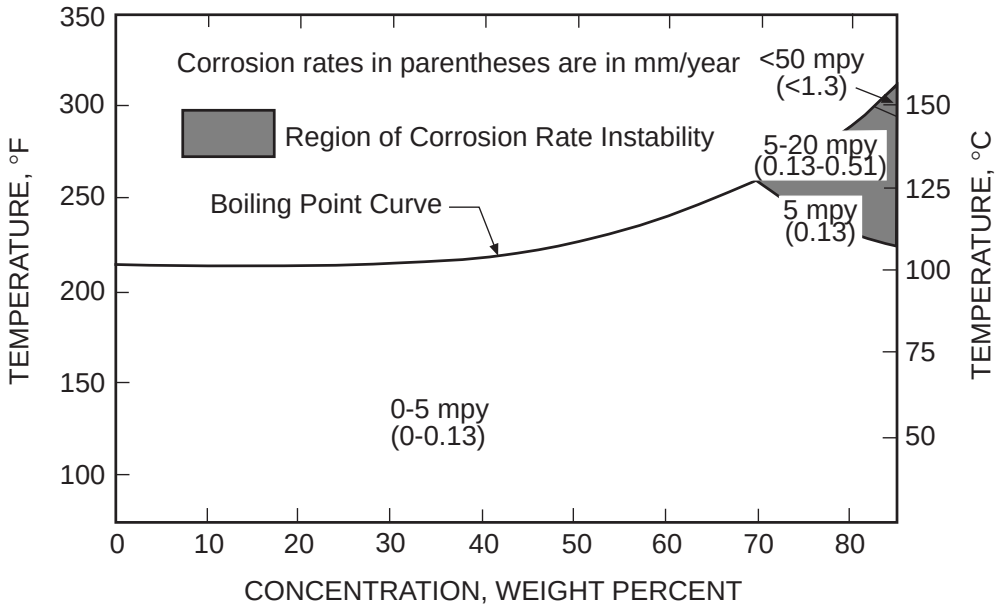
STRESS CORROSION

Stressed specimens were tested in a solution of boiling 42 percent magnesium chloride representing an accelerated chloride stress-corrosion cracking test. C-4 alloy went over 1000 hours without cracking.

ISOCORROSION DIAGRAMS*

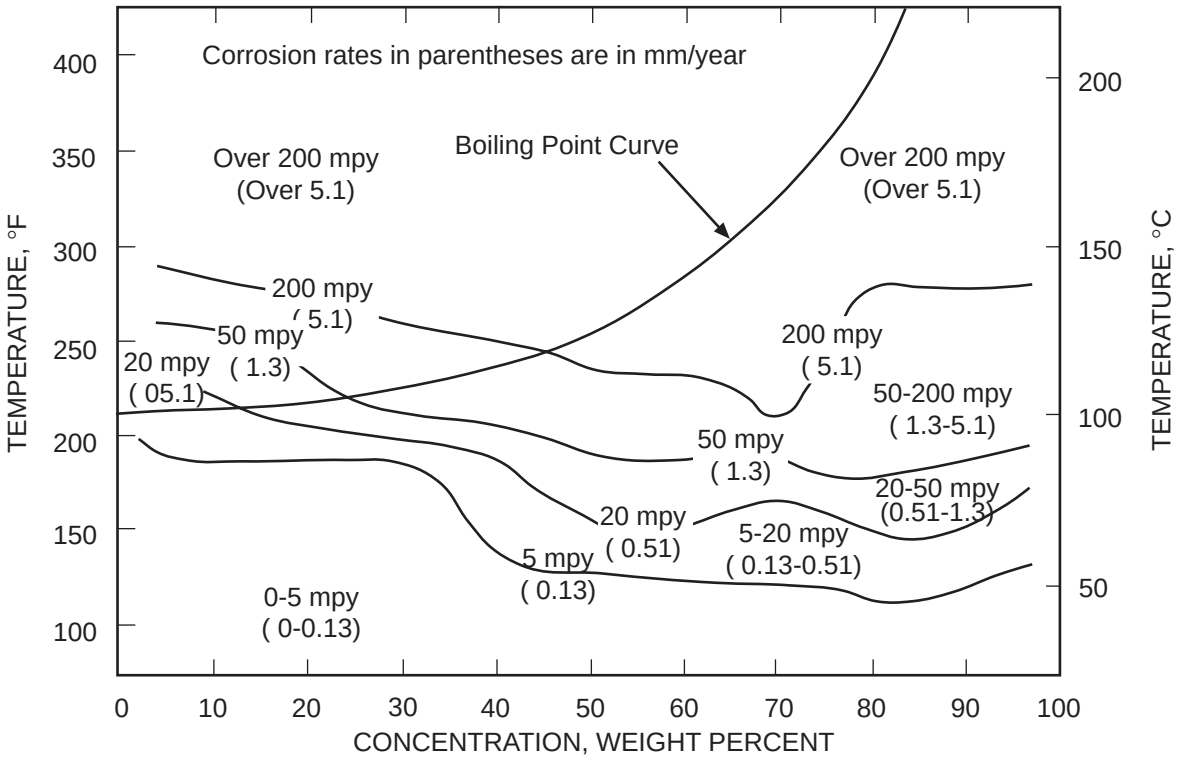
The isocorrosion diagrams shown on this and subsequent pages were plotted using data obtained in laboratory test in reagent grade acids. These data should be used only as a guide. It is recommended that samples be tested under actual plant conditions.

Resistance to Phosphoric Acid

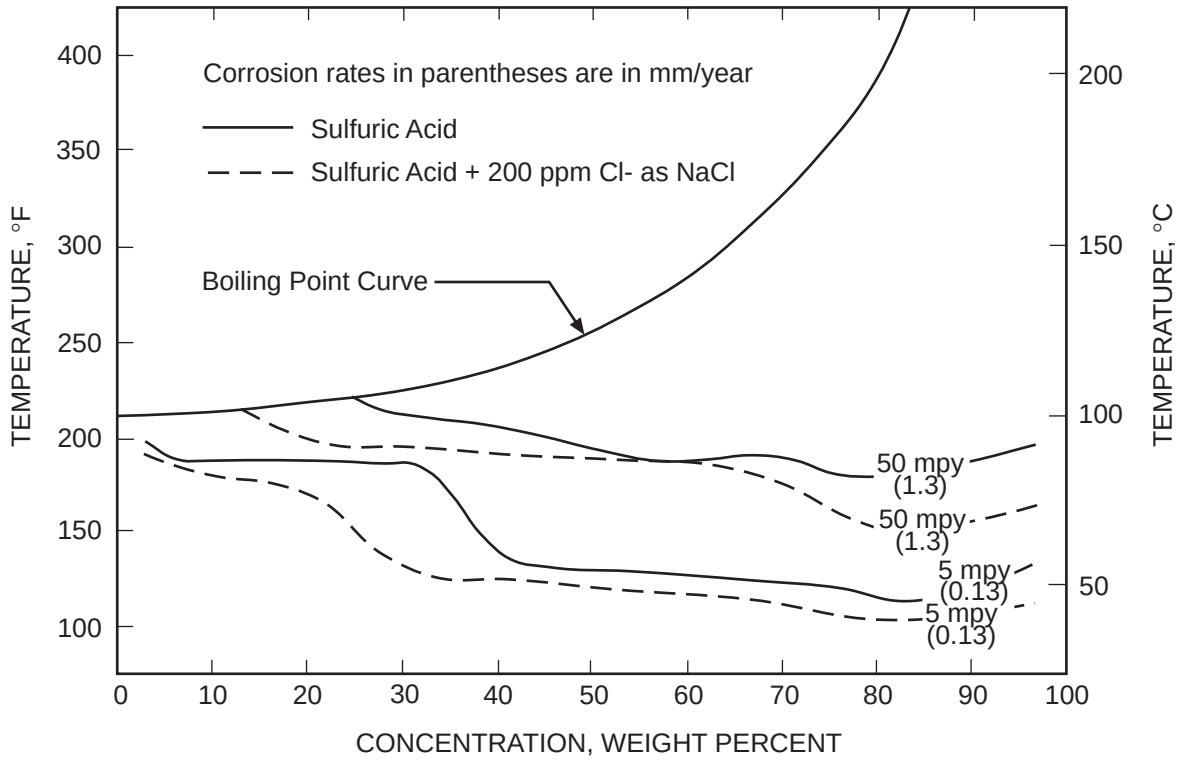


*All test specimens were solution heat-treated at 1950°F (1066°C), rapid quench and in the unwelded condition.

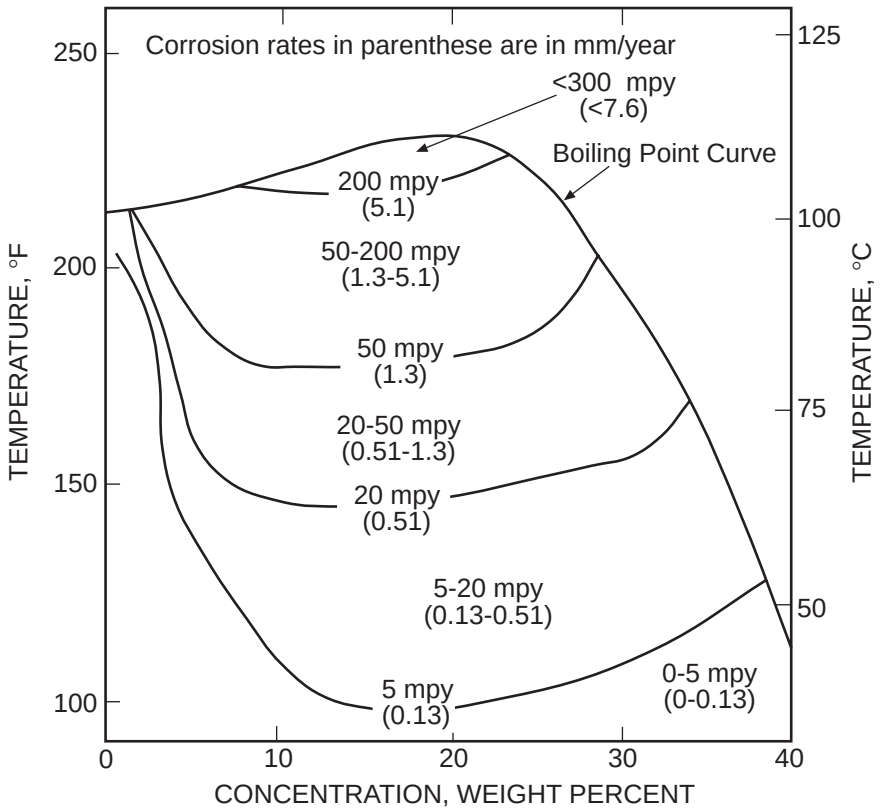
Resistance to Sulfuric Acid



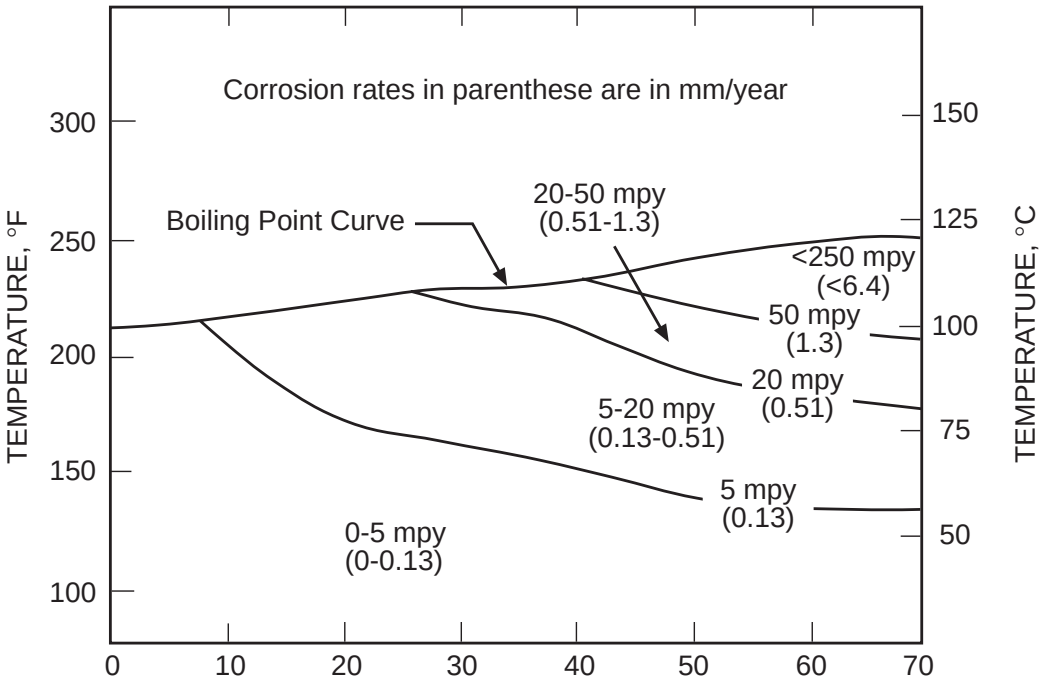
Resistance to Sulfuric Acid with 200 ppm Chloride Ions



Resistance to Hydrochloric Acid



Resistance to Nitric Acid



STANDARD PRODUCTS

By Brand or Alloy Designation:

HAYNES International

HASTELLOY® Family of Corrosion-Resistant Alloys

B-3®, C-4, C-22®, C-276, C-2000®, C-22HS®, G-30®, G-35®, G-50®, HYBRID-BC1™, and N

HASTELLOY Family of Heat-Resistant Alloys

S, W, and X

HAYNES® Family of Heat-Resistant Alloys

25, R-41, 75, HR-120®, HR-160®, 188, 214®, 230®, 230-W®, 242®, 263, 282®, 556®, 617, 625, 65SQ®, 718, X-750, MULTIMET®, NS-163™, and Waspaloy

Corrosion-Wear Resistant Alloy

ULTIMET®

Wear-Resistant Alloy

6B

HAYNES Titanium Alloy Tubular

Ti-3Al-2.5V

Standard Forms: Bar, Billet, Plate, Sheet, Strip, Coils, Seamless or Welded Pipe & Tubing, Pipe Fittings, Flanges, Fittings, Welding Wire, and Coated Electrodes

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