HASTELLOY® B-3® alloy

Principal Features

Exceptional resistance to HCl and H_2SO_4 and enhanced structural stability
HASTELLOY® B-3® alloy (UNS N10675) exhibits extremely high resistance to pure hydrochloric, hydrobromic, and sulfuric acids. Furthermore, it has greatly improved structural stability compared with previous B-type alloys, leading to fewer concerns during welding, fabrication, and service.

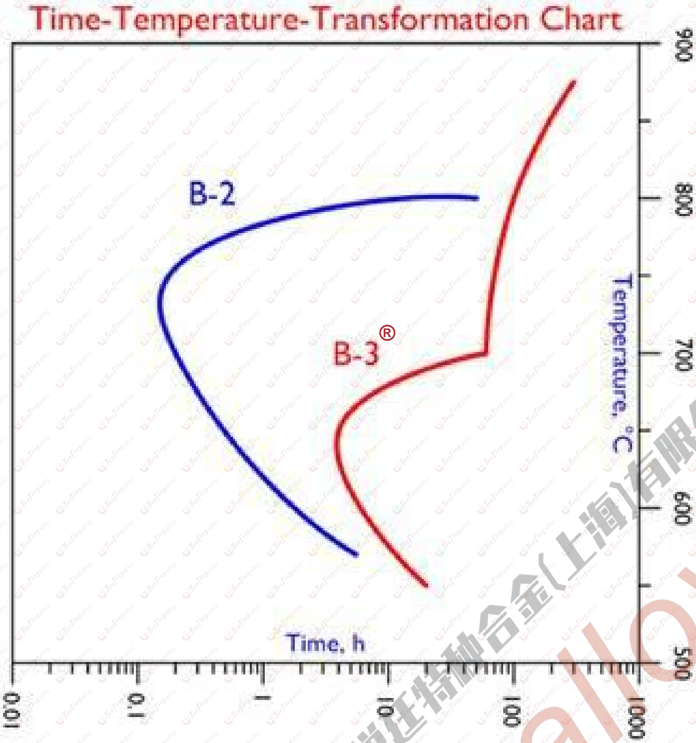
Like other nickel alloys (in the mill annealed condition), it is ductile, can be formed and welded, and resists stress corrosion cracking in chloride-bearing solutions. Also, it is able to withstand fluoride-bearing media and concentrated sulfuric acid, both of which result in damage to zirconium alloys.

It is used in numerous chemical process industry (CPI) applications, especially in the construction of reaction vessels for pure, reducing acid service.

Nominal Compostition

	Weight %
Nickel:	65 min.
Molybdenum:	28.5
Chromium:	1.5
Iron:	1.5
Tungsten:	3 max.
Manganese:	3 max.
Cobalt:	3 max.
Aluminum:	0.5 max.
Titanium:	0.2 max.
Silicon:	0.1 max.
Carbon:	0.01 max.
Niobium:	0.2 max.
Vanadium:	0.2 max.
Copper:	0.2 max.
Tantalum:	0.2 max.
Zirconium:	0.01 max.

Thermal Stability (T-T-T Chart)



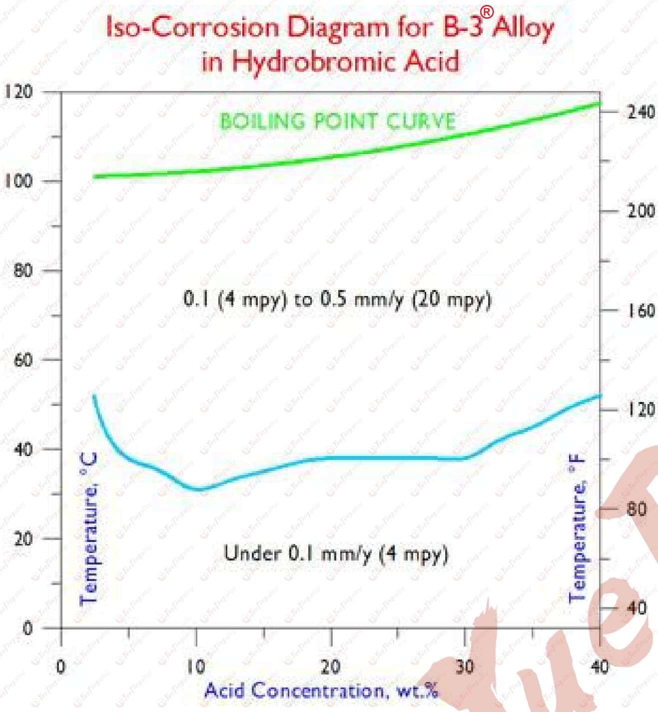
The molybdenum content of the nickel-molybdenum (B-type) alloys is such that there is a strong tendency for phases other than the desirable (face-centered cubic) gamma phase to form in the microstructure, particularly in the temperature range 500°C to 900°C. The most deleterious of these alternate phases is Ni_4Mo, which forms quickly at certain temperatures, affects ductility, and reduces resistance to stress corrosion cracking.

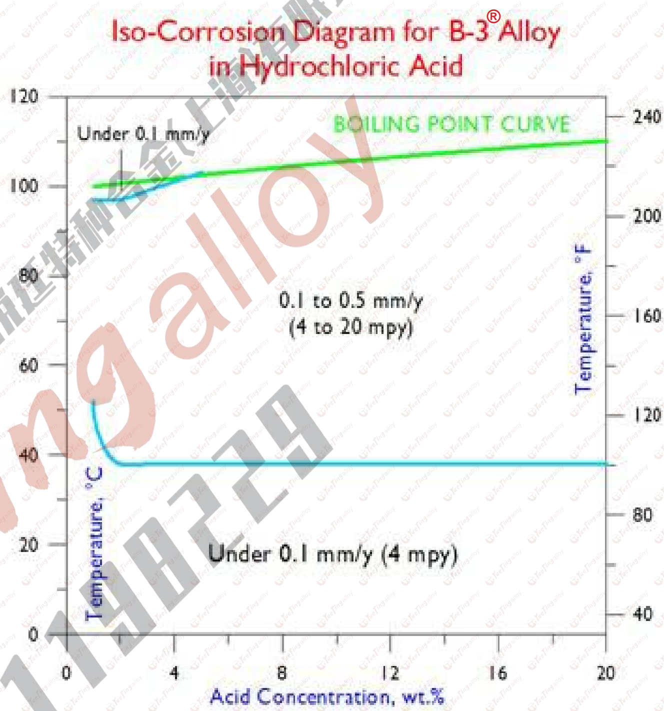
The chief attribute of B-3® alloy, as compared with other modern B-type materials, is its greatly improved structural stability (in particular its reduced susceptibility to Ni_4Mo).

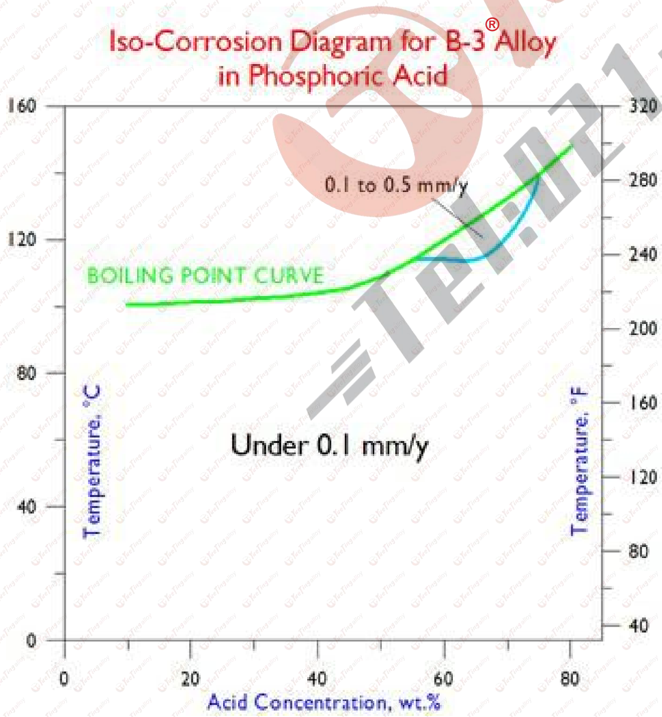
The time-temperature-transformation diagram shown above illustrates the advantages of B-3 alloy over its predecessor (B-2 alloy). Whereas B-2 alloy suffers from the rapid formation of Ni_4Mo at around 750°C, it takes several hours (at around 650°C), to induce deleterious second phases in B-3® alloy. This is due to the judicious use of minor elements and a shift in the molybdenum content, to induce the slowly-forming Ni_3Mo instead.

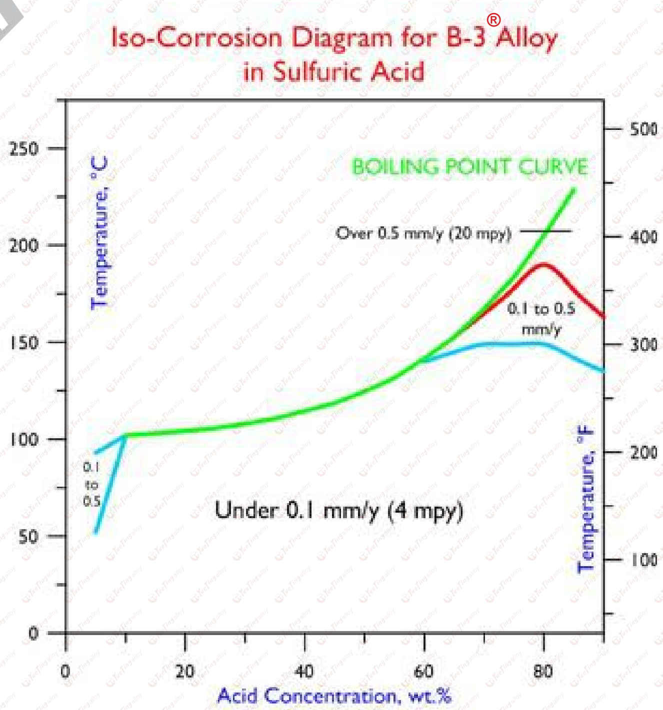
Iso-Corrosion Diagrams

Each of these iso-corrosion diagrams was constructed using numerous corrosion rate values, generated at different acid concentrations and temperatures (up to the boiling point). The blue line represents those combinations of acid concentration and temperature at which a corrosion rate of 0.1 mm/y (4 mils per year) is expected, based on laboratory tests in reagent grade acids. Below the line, rates under 0.1 mm/y are expected. The red line in the sulfuric acid diagram indicates the combinations of acid concentration and temperature at which a corrosion rate of 0.5 mm/y (20 mils per year) is expected. Above the red line, rates over 0.5 mm/y are expected. Between the blue and red lines, corrosion rates are expected to fall between 0.1 and 0.5 mm/y. These diagrams do not predict the corrosion rates above the boiling point curves.







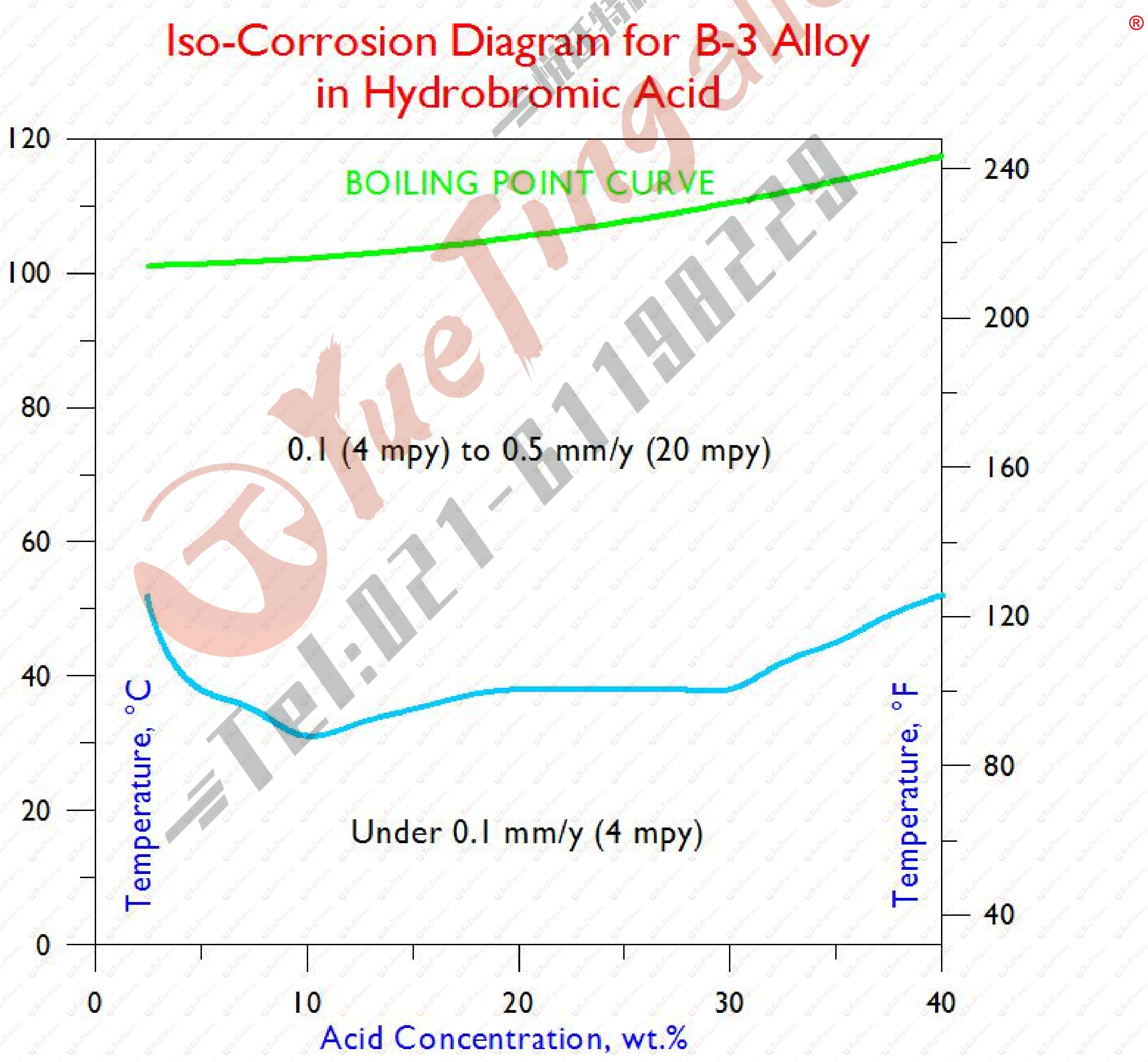


Selected Corrosion Data

Hydrobromic Acid

Conc. Wt.%	50°F 10°C	75°F 24°C	100°F 38°C	125°F 52°C	150°F 66°C	175°F 79°C	200°F 93°C	225°F 107°C	Boiling
2.5	-	-	0.07	0.11	0.26	-	0.24	-	0.02
5	-	0.04	0.1	-	0.27	-	0.25	-	0.03
7.5	-	-	-	-	-	-	-	-	-
10	-	0.05	0.15	-	0.29	-	0.28	-	0.1
15	-	-	-	-	-	-	-	-	-
20	-	0.04	0.12	0.19	0.27	-	0.27	-	0.1
25	-	-	-	-	-	-	-	-	-
30	-	0.03	0.1	0.15	0.2	-	0.29	-	0.29
40	-	0.02	0.06	0.11	0.16	-	0.25	-	0.43

All corrosion rates are in millimeters per year (mm/y); to convert to mils (thousandths of an inch) per year, divide by 0.0254.
Data are from Corrosion Laboratory Jobs 71-97, 26-99, and 49-99.
All tests were performed in reagent grade acids under laboratory conditions; field tests are encouraged prior to industrial use.



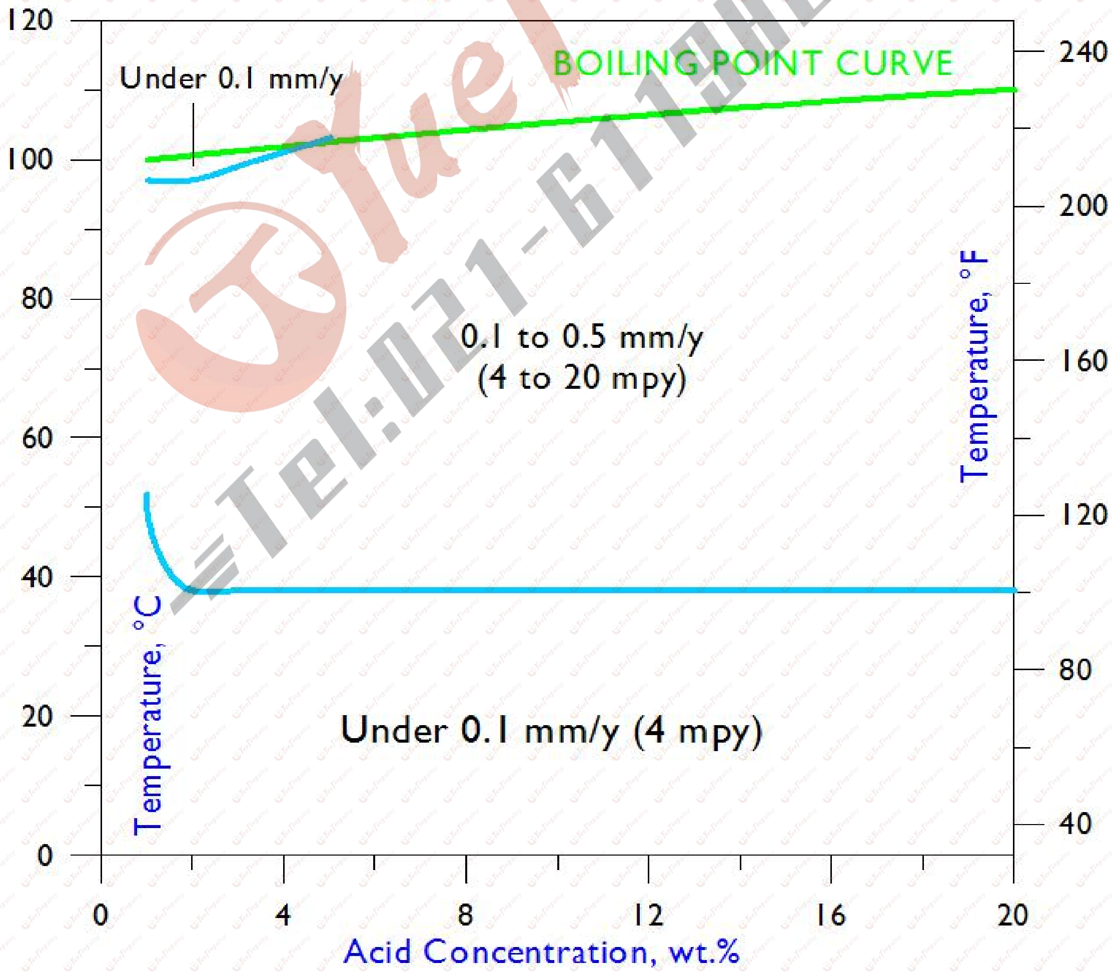
Selected Corrosion Data Continued

Hydrochloric Acid

Conc. Wt.%	50°F 10°C	75°F 24°C	100°F 38°C	125°F 52°C	150°F 66°C	175°F 79°C	200°F 93°C	225°F 107°C	Boiling
1	-	-	0.07	0.11	0.18	-	0.21	-	0.01
1.5	-	-	-	-	-	-	-	-	-
2	-	-	0.1	0.16	0.21	-	0.26	-	0.04
2.5	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
3.5	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
4.5	-	-	-	-	-	-	-	-	-
5	-	-	0.11	0.19	0.25	-	0.3	-	0.08
7.5	-	-	-	-	-	-	-	-	-
10	-	-	0.13	0.2	0.24	-	0.29	-	0.13
15	-	-	0.1	0.18	0.23	-	0.28	-	0.21
20	-	-	0.1	0.15	0.21	-	0.3	-	0.29

All corrosion rates are in millimeters per year (mm/y); to convert to mils (thousandths of an inch) per year, divide by 0.0254.
Data are from Corrosion Laboratory Jobs 37-92, 30-94, and 42-95.
All tests were performed in reagent grade acids under laboratory conditions; field tests are encouraged prior to industrial use.

Iso-Corrosion Diagram for B-3® Alloy in Hydrochloric Acid



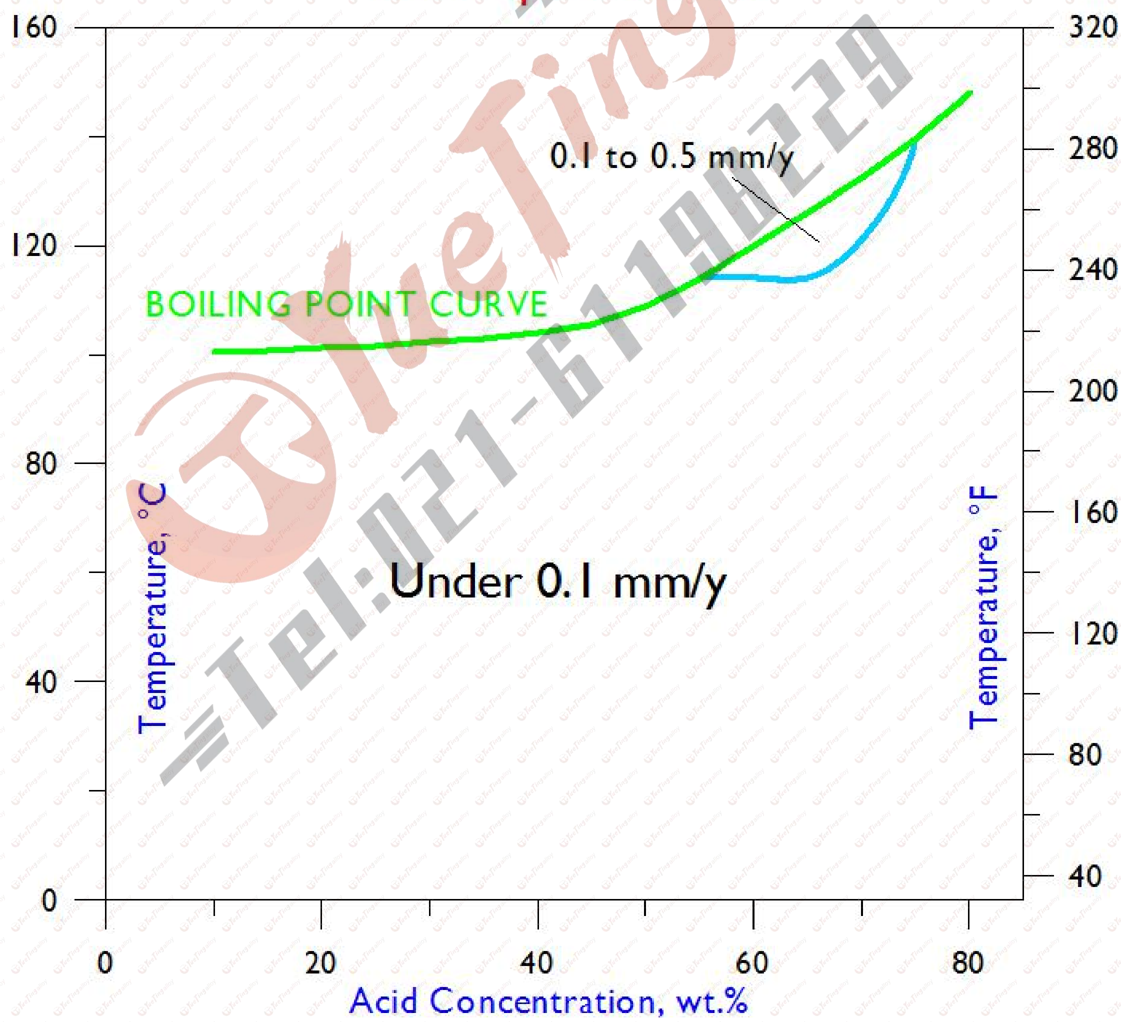
Selected Corrosion Data Continued

Phosphoric Acid

Conc. Wt.%	125°F 52°C	150°F 66°C	175°F 79°C	200°F 93°C	225°F 107°C	250°F 121°C	275°F 135°C	300°F 149°C	Boiling
10	-	-	-	-	-	-	-	-	0.07
30	-	-	-	-	-	-	-	-	0.07
50	-	-	-	0.03	-	-	-	-	0.09
60	-	-	-	0.03	-	-	-	-	0.14
65	-	-	-	-	-	-	-	-	-
70	-	-	-	0.02	-	0.08	-	-	0.21
75	-	-	-	-	-	-	0.04	-	-
80	-	-	-	0.02	-	0.09	0.05	-	0.04
85	-	-	-	0.02	-	0.07	0.04	0.08	0.1

All corrosion rates are in millimeters per year (mm/y); to convert to mils (thousandths of an inch) per year, divide by 0.0254.
Data are from Corrosion Laboratory Jobs 113-92, 31-94, and 47-97.
All tests were performed in reagent grade acids under laboratory conditions; field tests are encouraged prior to industrial use.

Iso-Corrosion Diagram for B-3 Alloy®
in Phosphoric Acid



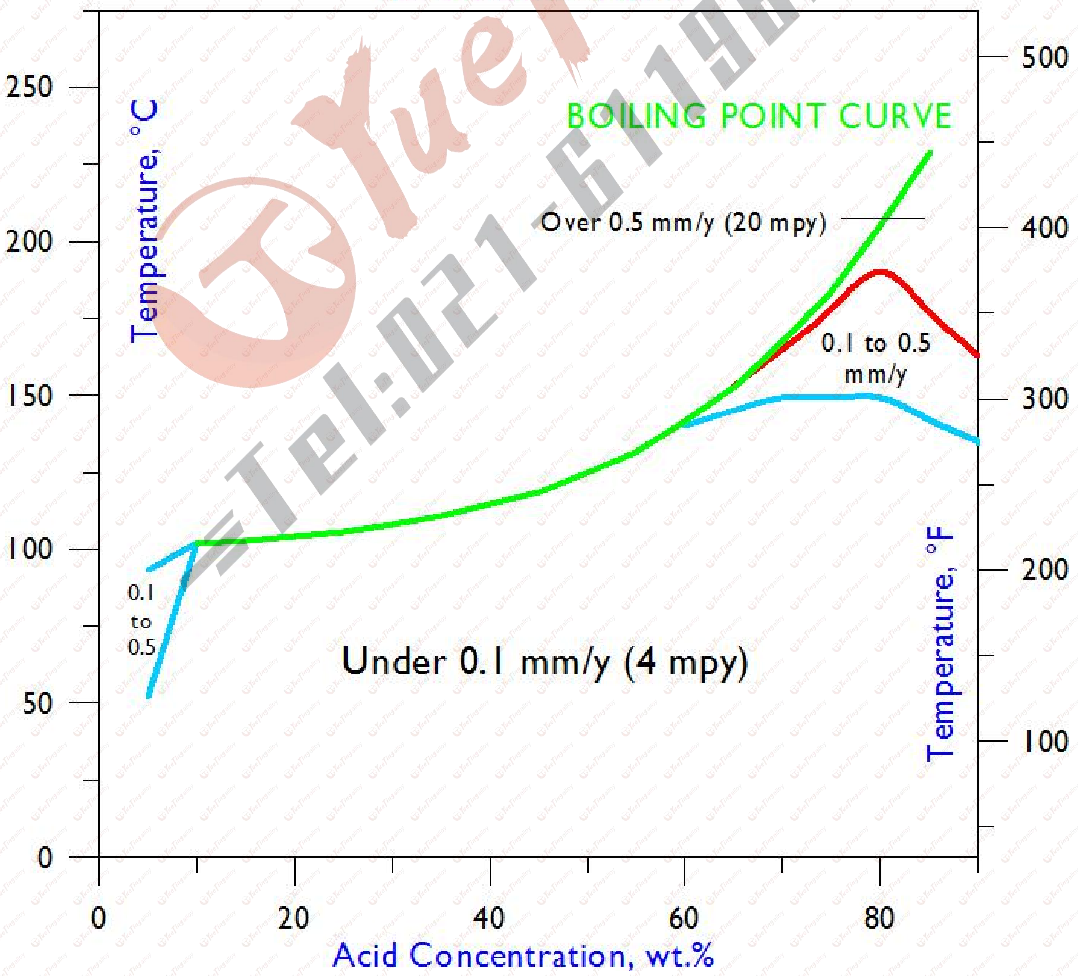
Selected Corrosion Data Continued

Sulfuric Acid

Conc. Wt.%	75°F 24°C	100°F 38°C	125°F 52°C	150°F 66°C	175°F 79°C	200°F 93°C	225°F 107°C	250°F 121°C	275°F 135°C	300°F 149°C	350°F 177°C	Boiling
1	-	-	-	-	-	-	-	-	-	-	-	-
2	-	0.07	0.09	0.13	0.11	0.1	-	-	-	-	-	0.01
3	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	-	0.07	0.08	0.15	0.13	0.11	-	-	-	-	-	0.01
10	-	0.04	0.08	0.11	0.11	0.11	-	-	-	-	-	0.01
20	-	0.03	-	0.08	-	0.11	-	-	-	-	-	0.02
30	-	0.02	-	0.06	-	0.09	-	-	-	-	-	0.02
40	-	-	-	0.03	-	0.06	-	-	-	-	-	0.02
50	-	-	-	0.03	-	0.04	-	-	-	-	-	0.03
60	-	-	-	0.02	-	0.03	-	-	-	-	-	0.05
70	-	-	-	-	-	0.01	-	0.03	-	0.11	-	0.15
80	-	-	-	-	-	0.01	-	0.03	-	0.08	0.44	4.76
90	-	-	-	-	-	0.02	-	0.05	0.11	0.14	0.76	-
96	-	-	-	-	-	0.02	-	0.09	0.22	0.35	2.59	-

All corrosion rates are in millimeters per year (mm/y); to convert to mils (thousandths of an inch) per year, divide by 0.0254.
Data are from Corrosion Laboratory Jobs 37-92, 29-94, 47-94, 42-95, and 14-96.
All tests were performed in reagent grade acids under laboratory conditions; field tests are encouraged prior to industrial use.

Iso-Corrosion Diagram for B-3® Alloy in Sulfuric Acid



Selected Corrosion Data (Reagent Grade Solutions, mm/y)

Chemical	Concentration wt.%	100°F 38°C	125°F 52°C	150°F 66°C	175°F 79°C	200°F 93°C	Boiling
Acetic Acid	10	-	-	-	-	-	0.01
	30	-	-	-	-	-	0.01
	50	-	-	-	-	-	0.01
	70	-	-	-	-	-	0.01
	99	-	-	-	-	-	0.02
Formic Acid	10	-	-	-	-	-	0.01
	20	-	-	-	-	-	0.02
	30	-	-	-	-	-	0.02
	40	-	-	-	-	-	0.01
	60	-	-	-	-	-	0.01
	89	-	-	-	-	-	0.01
Hydrobromic Acid	2.5	0.07	0.11	0.26	-	0.24	0.02
	5	0.1	-	0.27	-	0.25	0.03
	10	0.15	-	0.29	-	0.28	0.1
	20	0.12	0.19	0.27	-	0.27	0.1
	30	0.1	0.15	0.2	-	0.29	0.29
	40	0.06	0.11	0.16	-	0.25	0.43
Hydrochloric Acid	1	0.07	0.11	0.18	-	0.21	0.01
	2	0.1	0.16	0.21	-	0.26	0.04
	5	0.11	0.19	0.25	-	0.3	0.08
	10	0.13	0.2	0.24	-	0.29	0.13
	15	0.1	0.18	0.23	-	0.28	0.21
	20	0.1	0.15	0.21	-	0.3	0.29
Phosphoric Acid	10	-	-	-	-	-	0.07
	30	-	-	-	-	-	0.07
	50	-	-	-	-	0.03	0.09
	60	-	-	-	-	0.03	0.14
	70	-	-	-	-	0.02	0.21
	80	-	-	-	-	0.02	0.04
	85	-	-	-	-	0.02	0.1
Sulfuric Acid	10	0.04	0.08	0.11	0.11	0.11	0.01
	20	0.03	-	0.08	-	0.11	0.02
	30	0.02	-	0.06	-	0.09	0.02
	40	-	-	0.03	-	0.06	0.02
	50	-	-	0.03	-	0.04	0.03
	60	-	-	0.02	-	0.03	0.05
	70	-	-	-	-	0.01	0.15
	80	-	-	-	-	0.01	4.76
	90	-	-	-	-	0.02	-
	96	-	-	-	-	0.02	-

Resistance to Stress Corrosion Cracking

One of the chief attributes of the nickel alloys is their resistance to chloride-induced stress corrosion cracking. A common solution for assessing the resistance of materials to this extremely destructive form of attack is boiling 45% magnesium chloride (ASTM Standard G 36), typically with stressed U-bend samples. As is evident from the following results, the three nickel alloys, B-3®, C-276 and 625, are much more resistant to this form of attack than the comparative, austenitic stainless steels. The tests were stopped after 1,008 hours (six weeks).

Alloy	Time to Cracking
316L	2 h
254SMO®	24 h
625	No Cracking in 1,008 h
C-276	No Cracking in 1,008 h
B-3®	**No Cracking in 1,008 h**

Corrosion Resistance of Welds

To assess the resistance of welds to corrosion, Haynes International has chosen to test all-weld-metal samples, taken from the quadrants of cruciform assemblies, created us- ing multiple gas metal arc (MIG) weld passes. Predictably, the inhomogeneous nature of weld microstructures leads to higher corrosion rates (than with homogeneous, wrought products) in some environments. Nevertheless, HASTELLOY® B-3® alloy exhibits very high resistance to the key, inorganic acids, even in welded form, as shown in the following table:

Chemical	Concentration	Temperature		Corrosion Rate			
				Weld Metal		Wrought Base Metal	
	wt. %	°F	°C	mpy	mm/y	mpy	mm/y
H_2SO_4	30	200	93	3.5	0.09	3.5	0.09
H_2SO_4	50	200	93	5.1	0.13	1.6	0.04
H_2SO_4	70	200	93	1.2	0.03	0.4	0.01
H_2SO_4	90	200	93	1.8	0.02	0.8	0.02
HCl	5	200	93	11.8	0.3	11.8	0.3
HCl	10	200	93	11.4	0.29	11.4	0.29

Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.333 lb/in³	RT	9.22 g/cm³
Electrical Resistivity	RT	53.8 µohm.in	RT	1.37 µohm.m
	200°F	53.9 µohm.in	100°C	1.37 µohm.m
	400°F	54.1 µohm.in	200°C	1.37 µohm.m
	600°F	54.3 µohm.in	300°C	1.38 µohm.m
	800°F	54.4 µohm.in	400°C	1.38 µohm.m
	1000°F	55.4 µohm.in	500°C	1.40 µohm.m
	1200°F	57.5 µohm.in	600°C	1.43 µohm.m
Thermal Conductivity	RT	78 Btu.in/h.ft².°F	RT	11.2 W/m.°C
	200°F	83 Btu.in/h.ft².°F	100°C	12.1 W/m.°C
	400°F	93 Btu.in/h.ft².°F	200°C	13.4 W/m.°C
	600°F	104 Btu.in/h.ft².°F	300°C	14.8 W/m.°C
	800°F	116 Btu.in/h.ft².°F	400°C	16.3 W/m.°C
	1000°F	129 Btu.in/h.ft².°F	500°C	17.9 W/m.°C
	1200°F	142 Btu.in/h.ft².°F	600°C	19.6 W/m.°C
Mean Coefficient of Thermal Expansion	77-200°F	5.7 µin/in.°F	25-100°C	10.6 µm/m.°C
	77-400°F	6.1 µin/in.°F	25-200°C	11.1 µm/m.°C
	77-600°F	6.3 µin/in.°F	25-300°C	11.4 µm/m.°C
	77-800°F	6.5 µin/in.°F	25-400°C	11.6 µm/m.°C
	77-1000°F	6.6 µin/in.°F	25-500°C	11.8 µm/m.°C
	77-1200°F	6.5 µin/in.°F	25-600°C	11.8 µm/m.°C
Specific Heat	RT	0.089 Btu/lb.°F	RT	373 J/kg.°C
	200°F	0.092 Btu/lb.°F	100°C	382 J/kg.°C
	400°F	0.098 Btu/lb.°F	200°C	409 J/kg.°C
	600°F	0.102 Btu/lb.°F	300°C	421 J/kg.°C
	800°F	0.104 Btu/lb.°F	400°C	431 J/kg.°C
	1000°F	0.104 Btu/lb.°F	500°C	436 J/kg.°C
	1200°F	0.112 Btu/lb.°F	600°C	434 J/kg.°C
Dynamic Modulus of Elasticity	RT	31.4 x 10⁶psi	RT	216 GPa
	200°F	30.9 x 10⁶psi	100°C	213 GPa
	400°F	30.1 x 10⁶psi	200°C	208 GPa
	600°F	29.3 x 10⁶psi	300°C	202 GPa
	800°F	28.3 x 10⁶psi	400°C	197 GPa
	1000°F	27.2 x 10⁶psi	500°C	190 GPa
	1200°F	26.5 x 10⁶psi	600°C	185 GPa
Melting Range	2500-2585°F	-	1370-1418°C	-

RT= Room Temperature

Impact Strength

Form	Thickness/Diameter		Test Temperature		Impact Strength		Number of Tests
-	in	mm	°F	°C	ft.lbf	J	-
Plate	0.79	20	RT	RT	353	479	3
Plate	0.79	20	-320	-196	334	453	3
Plate	1.38	35	RT	RT	388	526	3
Plate	1.38	35	-320	-196	359	487	3
Bar	1.58	40	RT	RT	388	526	3
Bar	1.58	40	-320	-196	339	460	3
Bar	1.97	50	RT	RT	390	529	3
Bar	1.97	50	-320	-196	338	458	3

*Charpy V-Notch Samples. RT= Room Temperature

Tensile Strength & Elongation

Form	Thickness		Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
	in	mm	°F	°C	ksi	MPa	ksi	MPa	%
Sheet	0.125	3.2	RT	RT	61	421	125	862	53
Sheet	0.125	3.2	200	93	55	379	121	834	57
Sheet	0.125	3.2	400	204	47	324	110	758	60
Sheet	0.125	3.2	600	316	44	303	104	717	63
Sheet	0.125	3.2	800	427	42	290	102	703	62
Sheet	0.125	3.2	1000	538	39	269	98	676	59
Sheet	0.125	3.2	1200	649	46	317	104	717	56
Plate	Multiple*		RT	RT	58	400	128	883	58
Plate	Multiple*		200	93	54	372	122	841	58
Plate	Multiple*		400	204	48	331	115	793	61
Plate	Multiple*		600	316	44	303	111	765	62
Plate	Multiple*		800	427	41	283	108	745	62
Plate	Multiple*		1000	538	40	276	106	731	62
Plate	Multiple*		1200	649	42	290	107	738	65

*Average values from the testing of 6 lots of plate (of different thicknesses) from three heats.
RT= Room Temperature

Welding & Fabrication

HASTELLOY® B-3® alloy is very amenable to the Gas Metal Arc (GMA/MIG), Gas Tungsten Arc (GTA/TIG), and Shielded Metal Arc (SMA/Stick) welding processes. Matching filler metals (i.e. solid wires and coated electrodes) are available for these processes, and welding guidelines are given in our “Welding and Fabrication” brochure.

Wrought products of HASTELLOY® B-3® alloy are supplied in the Mill Annealed (MA) condition, unless otherwise specified. This solution annealing procedure has been designed to optimize the alloy’s corrosion resistance and ductility. Following all hot forming operations, the material should be re-annealed, to restore optimum properties. In the case of cold-formed components of B-3® alloy, solution annealing should be performed prior to subsequent fabrication/welding when cold work is greater than about 7%. Otherwise, B-3® alloy is very susceptible to cracking in the welded region during subsequent fabrication/welding. The cracking may not become obvious until the component has been put into service. Care should also be taken to utilize well-controlled furnace annealing conditions: fast heat-up rate, precise temperature control, and rapid cooling.

The annealing temperature for HASTELLOY® B-3® alloy is 1066°C (1950°F), and water quenching is advised (rapid air cooling is feasible with structures thinner than 10 mm (0.375 in). A hold time at the annealing temperature of 10 to 30 minutes is recommended, depending on the thickness of the structure (thicker structures need the full 30 minutes). More details concerning the heat treatment of HASTELLOY® B-3® alloy are given in our “Welding and Fabrication” brochure.

HASTELLOY® B-3® alloy can be hot forged, hot rolled, hot upset, hot extruded, and hot formed. However, it is more sensitive to strain and strain rates than the austenitic stainless steels, and the hot working temperature range is quite narrow. For example, the recommended start temperature for hot forging is 1232°C (2250°F) and the recommended finish temperature is 982°C (1800°F). Moderate reductions and frequent re-heating provide the best results, as described in our “Welding and Fabrication” brochure. This reference also provides guidelines for cold forming, spinning, drop hammering, punching, and shearing. The alloy is stiffer than most austenitic stainless steels, and more energy is required during cold forming. Also, HASTELLOY® B-3® alloy work hardens more readily than most austenitic stainless steels, and may require several stages of cold work, with intermediate anneals.

While cold work does not usually affect the resistance of HASTELLOY® B-3® alloy to general corrosion, it can affect resistance to stress corrosion cracking. For optimum corrosion performance, therefore, the re-annealing of cold worked parts (following an outer fiber elongation of 7% or more) is important.

Specifications & Codes

Specifications

HASTELLOY® B-3® alloy (N10675, W80675)	
Sheet, Plate & Strip	SB 333/B 333 P=44
Billet, Rod & Bar	SB 335/B 335 B472 P= 44
Coated Electrodes	SFA 5.11/A 5.11 (ENiMo-10) DIN 2.4696 (EL-NiMo28Cr) F= 44
Bare Welding Rods & Wire	SFA 5.14/ A 5.14 (ERNiMo-10) DIN 2.4695 (SG-NiMo30Cr) F= 44
Seamless Pipe & Tube	SB 622/B 622 P= 44
Welded Pipe & Tube	SB 619/B 619 SB 626/B 626 P= 44
Fittings	SB 366/B 366 SB 462/B 462 P= 44
Forgings	SB 564/B 564 SB 462/B 462 P= 44
DIN	17744 No. 2.4600 NiMo29Cr
TÜV	Werkstoffblatt 517 Kennblatt 7615 Kennblatt 7616 Kennblatt 7617
Others	-

Codes

HASTELLOY® B-3® alloy (N10675, W80675)			
ASME	Section I	-	
	Section III	Class 1	-
		Class 2	-
		Class 3	800°F (427°C)[2]
	Section VIII	Div. 1	800°F (427°C)[1]
		Div. 2	-
	Sections XII	650°F (343°C)[4]	
	B16.5	800°F (427°C)[6] Blt	
	B16.34	800°F (427°C)[5]	
	B31.1	-	
	B31.3	800°F (427°C)[3]	
VdTÜV (doc #)		752°F (400°C)[7], #517	

[1]Approved material forms: Plate, Sheet, Bar, Forgings, fittings, welded pipe/tube, seamless pipe/tube
[2]Approved material forms: Plate, Sheet, Bar, Forgings, welded pipe/tube, seamless pipe/tube
[3]Approved material forms: Plate, Sheet, Bar, fittings, welded pipe/tube, seamless pipe/tube
[4]Approved material forms: Plate, Sheet, Bar, Forgings, fittings, welded pipe/tube
[5]Approved material forms: Plate, Bar, Forgings, seamless pipe/tube, Bolting
[6]Approved material forms: Plate, Forgings, fittings, Bolting
[7]Approved material forms: Plate, Sheet, Bar, Forgings