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HAYNES International CORROSION-RESISTANT ALLOYS

HASTELLOY® C-22® alloy

A most versatile nickel-chromium-molybdenum-tungsten alloy available today with improved resistance to both uniform and localized corrosion as well as to a variety of mixed industrial chemicals. The C-22 alloy exhibits superior weldability and is used as overalloy filler wire and weld overlay consumables to improve resistance to corrosion.

Contents

H-2019F

About Haynes International, Inc.

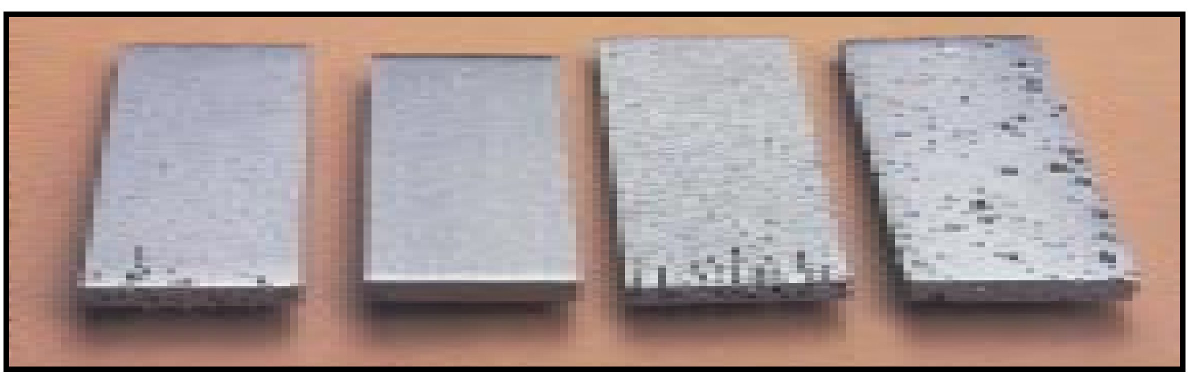
Haynes International, Inc., was founded in 1912 by Elwood Haynes, an inventor of some of the first cobalt-based alloys. The company has relied on a strong technology base ever since.

HASTELLOY® alloys are known throughout the chemical process industry as the premier corrosion resistant materials. HAYNES® high-temperature alloys are equally well known in the aerospace field for their unique heat-resistance qualities. Both of these groups of alloys were developed and perfected in Kokomo, Indiana.

Haynes International is stocked to respond immediately to virtually any high performance alloy requirement. The company's technical backup and applications knowledge are unsurpassed.

HASTELLOY® C-22® alloy Excels in Pitting Resistance

HASTELLOY® C-4 alloy | HASTELLOY C-22 alloy | HASTELLOY C-276 alloy | HAYNES® 625 alloy



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

PRINCIPAL FEATURES

Outstanding Corrosion Resistance

HASTELLOY® C-22® alloy is a versatile nickel-chromium-molybdenum-tungsten alloy with better overall corrosion resistance than other Ni-Cr-Mo alloys available today, including HASTELLOY C-276 and C-4 alloys and alloy 625. C-22 alloy has outstanding resistance to pitting, crevice corrosion, and stress corrosion cracking. It has excellent resistance to oxidizing aqueous media including wet chlorine and mixtures containing nitric acid or oxidizing acids with chloride ions. Also, C-22 alloy offers optimum resistance to environments where reducing and oxidizing conditions are encountered in process streams. Because of such versatility it can be used where "upset" conditions are likely to occur or in multi-purpose plants.

C-22 alloy has exceptional resistance to a wide variety of chemical process environments, including strong oxidizers such as ferric and cupric chlorides, chlorine, hot contaminated solutions (organic and inorganic), formic and acetic acids, acetic anhydride, and seawater and brine solutions. C-22 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.

Product Forms

C-22 alloy is available in most common product forms: plate, sheet, strip, billet, bar, wire, covered electrodes, pipe, and tubing.

Wrought forms of this alloy are furnished in the solution heat-treated condition unless otherwise specified.

Applications

Some of the areas of use for C-22 alloy are:

- Acetic Acid/Acetic Anhydride
- Acid Etching
- Cellophane Manufacturing
- Chlorination Systems
- Complex Acid Mixtures
- Electro-Galvanizing Rolls
- Expansion Bellows
- Flue Gas Scrubber Systems
- Geothermal Wells
- HF Furnace Scrubbers
- Incineration Scrubber Systems
- Nuclear Fuel Reprocessing
- Pesticide Production
- Phosphoric Acid Production
- Pickling Systems
- Plate Heat Exchangers
- Selective Leaching Systems
- SO_2 Cooling Towers
- Sulfonation Systems
- Tubular Heat Exchangers
- Weld Overlay-Valves

Field Test Program

Samples of C-22 alloy are readily available for laboratory or inplant corrosion testing. Analysis of corrosion resistance of the tested material can also be performed and the results provided to the customer as a free technical service. Test C-22 alloy and compare. Contact any of the convenient locations shown on the back cover of this brochure for test coupons and information.

Specifications

HASTELLOY C-22 alloy is covered by ASME Section VIII, Division I. Plate, sheet, strip, bar, tubing, and pipe are covered by ASME specifications SB-574, SB-575, SB-619, SB-622 and SB-626 and by ASTM specifications B-574, B-575, B-619, B-622, and B-626. DIN specification is 17744 No. 2.4602 (all forms), TUV Werkstoffblatt 479 (all forms). C-22 alloy falls within the range of UNS number N06022 but has a more restricted composition for improved performance. These improvements are of such significance that it has been widely patented throughout the world.

Material Safety Data Sheets

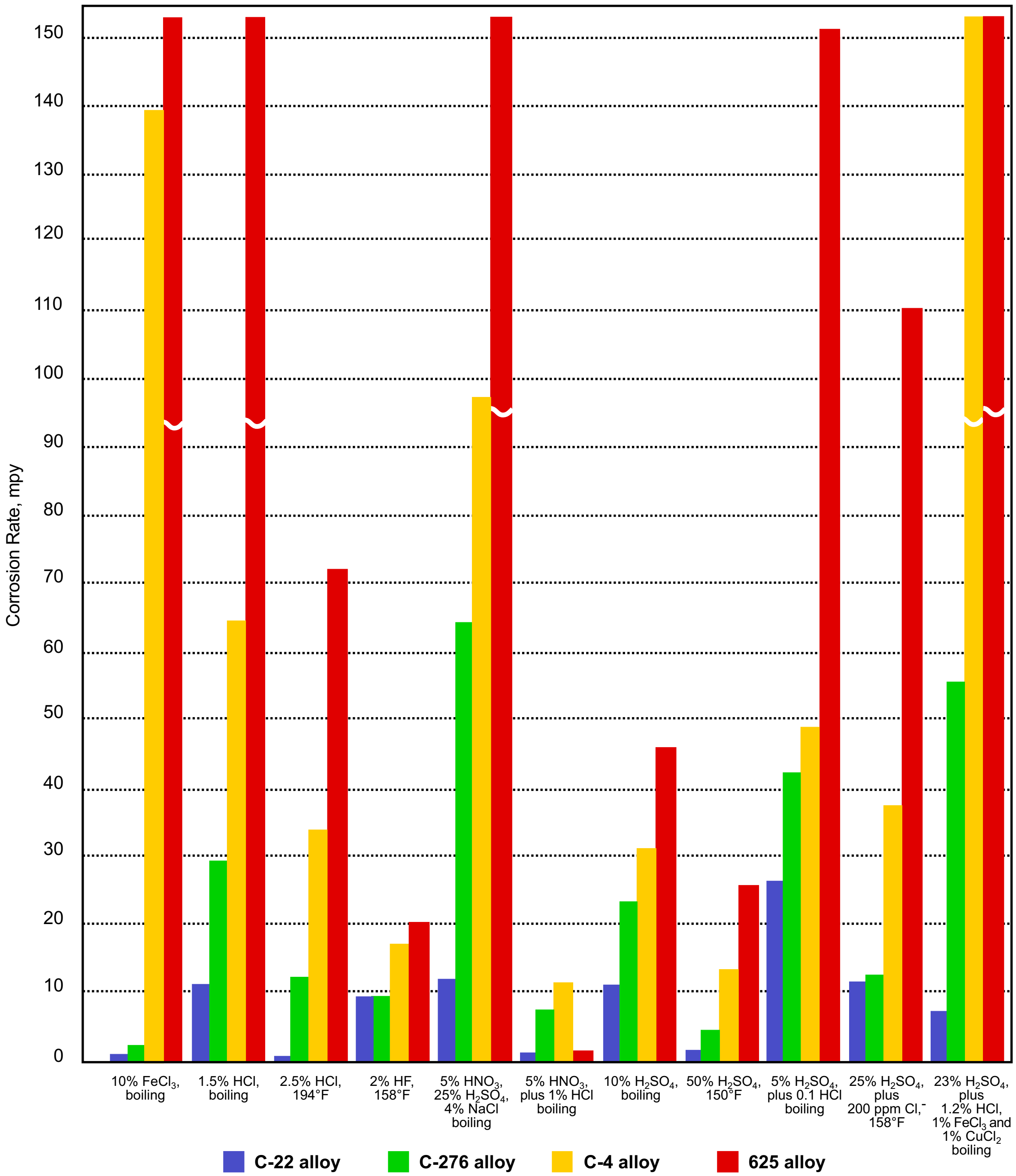
For information concerning material safety data, ask for Material Safety Data Sheets H2071 and H1072.

Nominal Chemical Composition, Weight Percent

Ni	Co	Cr	Mo	W	Fe	Si	Mn	C	V
56[a]	2.5**	22	13	3	3	0.08**	0.50**	0.010**	0.35**

* The undiluted deposited chemical composition of C-22 alloy covered electrodes has 0.02% carbon and 0.2% Si.
** Maximum [a] As balance

Laboratory Corrosion Tests Demonstrate Superiority of HASTELLOY® C-22® alloy



Field Evaluations

Exhibits Excellent Corrosion Protection

Chemical Processing Industry

Reactor Vessel
10-15% Sulfuric Acid + Solids/Impurities
212°F (100°C) — 12 Months

	Corrosion Rate (mpy)	Remarks
316L Stainless Steel	>61	Sample Dissolved
Carpenter 20Cb-3® alloy	>57	Sample Dissolved
Alloy 825	>58	Sample Dissolved
HASTELLOY® B-2 alloy	>58	Sample Dissolved
HAYNES® 625 alloy	29	Severe Corrosion Attack
HASTELLOY C-276 alloy	28	Severe Corrosion Attack
HASTELLOY C-22® alloy	4.7	Slight Corrosion Attack

Flue Gas Desulfurization (FGD)

Pulverized Coal Fired Unit
4.8% Sulfur
Outlet Duct
129°F (54°C) — 27 Months

	Depth of Attack	
	Pitting (in.)	Crevice (in.)
316L Stainless Steel	0.011	0.015
Alloy 904L	0.010	0.005
Jessop JS700® alloy	0.010	0.011
HAYNES 625 alloy	No Attack	0.005
HASTELLOY C276 alloy	No Attack	0.007
HASTELLOY C-22 alloy	No Attack	0.002

Refinery Industry

Coke Refinery
Vaporizer
203°F (95°C) — 2 Months

	Corrosion Rate (mpy)	Remarks
316L Stainless Steel	139	Severe Crevice Attack
Carpenter 20Cb-3® alloy	227	Partially Dissolved
Avesta 254 SMO® alloy	83	Pitting, Crevice Attack
Allegheny AL-6XN® alloy	60	Pitting, Crevice Attack
HAYNES 625 alloy	29	Pitting, Crevice Attack
HASTELLOY C-22 alloy	3.4	Slight Crevice Attack

Chemical Waste Incineration

Rotary Kiln Industrial Organic
Quench Duct
300°F (149°C) — 4 Months

	Corrosion Rate (mpy)	Remarks
Carbon Steel	>353	Sample Dissolved
316L Stainless Steel	>160	Sample Dissolved
Avesta 254 SMO alloy	83	Severe Pitting Attack
HAYNES 625 alloy	64	Moderate Pitting Attack
HASTELLOY C-276 alloy	53	Moderate Pitting Attack
HASTELLOY C-22 alloy	27	Slight Pitting Attack

Pulp and Paper Industry

Ammonium Sulfite-Type Mill
C-Stage Washer
75°F (24°C) — 8 Months

	Depth of Attack	
	Pitting (in.)	Crevice (in.)
316L Stainless Steel	0.030	0.045
Alloy 904L	0.023	0.029
Avesta 254 SMO alloy	0.015	No Attack
HAYNES 625 alloy	0.005	No Attack
HASTELLOY C-22 alloy	0.002	No Attack

Chemical Waste Incineration

Ammonia Stripping Process
Waste Water
160°F (71°C) — 3 Months

	Depth of Attack	
	Pitting (in.)	Crevice (in.)
Carbon Steel	0.040	0.050
316L Stainless Steel	0.005	0.005
Allegheny AL-6XN alloy	0.005	No Attack
HAYNES 625 alloy	0.004	No Attack
HASTELLOY C-22 alloy	No Attack	No Attack

TYPICAL APPLICATIONS

This large fabrication of HASTELLOY® C-22® alloy is shown here being readied for shipment to a papermill in the southeast. C-22 alloy was selected for this application after extensive testing in the actual bleach washer environment. It has already given over 10 years of service with no corrosive attack.

Twenty different materials were tested for this hydrofluoric acid prescrubber after the original material failed. C-22 alloy had four times better corrosion resistance than the original material and 20 percent better than the next candidate. The process involves 20 percent HF, 64 percent H_2SO_4 and 16 percent water at 150 to 200°F.

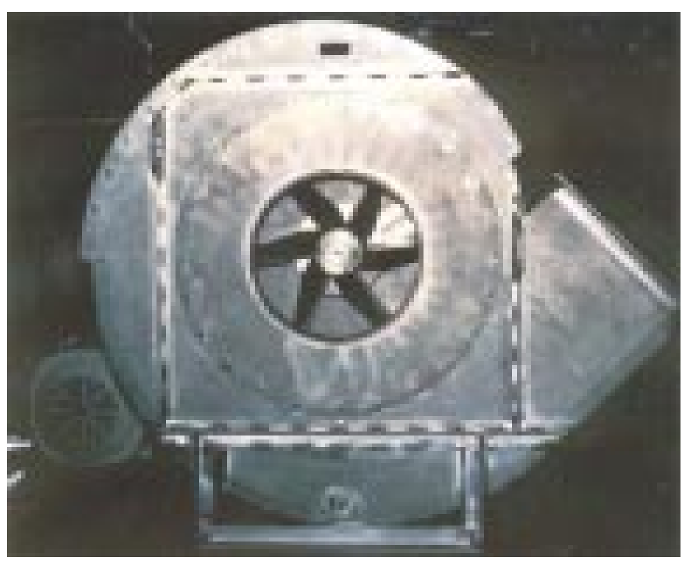
Solid rocket propellant effluents and salt air caused pitting and crevice corrosion attack of stainless steel. C-22 alloy was selected over 19 different alloys for the clamshell bellows after extensive testing. The bellows have been in service for more than 12 years.

Sleeved electrogalvanizing finishing rolls made of HASTELLOY C-22 alloy are ready for placement in a steel finishing manufacturing line. C-22 alloy helps reduce defects on the rolls which is necessary to produce defect free galvanized steel for the automotive industry.

Acid pump, fortified with a C-22 alloy sleeve, is still providing excellent service after 9 years in a continuous stainless steel pickling operation. The acid consists of 2 percent hydrofluoric acid, 20 percent hydrochloric acid, and as much as 40 gm/liter of iron, at 170°F.

Conditions were so severe in C-stage bleaching operations at one mill that even C-276 alloy welds were suspect. As a preventive maintenance measure, 3 mm was ground off each weld and replaced with a weld deposit of C-22 alloy. This photo, taken 18 months later, shows the welds virtually unaffected. At this printing, it is still in service after 7 years.

The largest fabrication of HASTELLOY® C-22® alloy known to-date is shown here being thin-sheet lined for exposure in a utility flue-gas desulfurization plant. C-22 sheet is still providing excellent service after 10 years.



C-22 alloy was selected to replace a FRP fan because of its durability and corrosion resistance. This fan will handle the incineration of radioactive and hazardous wastes.

COMPARATIVE AQUEOUS CORROSION DATA*

Media	Concentration Weight Percent	Test Temperature °F	Test Temperature (°C)	Average Corrosion Rate Per Year, mils** C-22® alloy	C-276 alloy	C-4 alloy	625 alloy
Acetic Acid	99	Boiling		Nil	<1	Nil	<1
Ferric Chloride	10	Boiling		1	2	140	7325
Formic Acid	88	Boiling		<1	1	2	9
Hydrochloric Acid	1	Boiling		3	13	25	1
	1.5	Boiling		14	32	64	353
	2	194	(90)	Nil	1	31	Nil
	2	Boiling		61	51	82	557
	2.5	194	(90)	<1	12	34	72
	2.5	Boiling		141	85	44	605
	10	Boiling		400	288	228	642
Hydrochloric Acid + 42 g/l $Fe_2(SO_4)_3$	1	200	(93)	2	41	-	238
	5	150	(66)	2	5	3	2
Hydrochloric Acid + 2% HF	5	158	(70)	59	26	34	123
Hydrofluoric Acid	2	158	(70)	9	9	17	20
	5	158	(70)	14	10	15	16
P_2O_5 (Commercial Grade)	38	185	(85)	2	9	-	1
	44	240	(116)	21	100	-	23
	52	240	(116)	11	33	-	12
P_2O_5 + 2000 ppm Cl	38	185	(85)	1	12	-	2
P_2O_5 + 0.5% HF	38	185	(85)	7	45	-	9
Nitric Acid	10	Boiling		<1	7	7	<1
	65	Boiling		134	888	217	21
Nitric Acid + 6% HF	5	140	(60)	67	207	204	73
Nitric Acid + 25% H_2SO_4 + 4% NaCl	5	Boiling		12	64	97	713
Nitric Acid + 1% HCl	5	Boiling		<1	8	11	1
Nitric Acid + 2.5% HCl	5	Boiling		2	21	26	<1
Nitric Acid + 15.8% HCl	8.8	126	(52)	4	33	114	>10,000

*Average of 4-10 tests.
**To convert mils per year (mpy) to mm per year, divide by 40.

Comparative Aqueous Corrosion Data* (continued)

Media	Concentration Weight Percent	Test Temperature °F	(°C)	C-22® alloy	C-276 alloy	C-4 alloy	625 alloy
Sulfuric Acid	2	150	(66)	Nil	<1	Nil	Nil
	2	Boiling		5	6	6	6
	5	174	(79)	<1	1	1	<1
	5	Boiling		9	12	16	16
	10	Boiling		12	19	25	37
	20	150	(66)	<1	<1	<1	<1
	20	174	(79)	1	3	2	13
	20	Boiling		33	39	36	91
	30	150	(66)	<1	1	<1	<1
	30	174	(79)	3	4	3	27
	30	Boiling		64	55	73	227
	40	100	(38)	<1	<1	<1	<1
	40	150	(66)	<1	1	9	1
	40	174	(79)	9	10	15	35
	50	100	(38)	<1	Nil	<1	1
	50	150	(66)	1	4	13	25
	50	174	(79)	16	12	25	58
	60	100	(38)	<1	<1	1	<1
	70	100	(38)	Nil	Nil	2	<1
	80	100	(38)	Nil	<1	<1	<1
Sulfuric Acid + 0.1% HCl	5	Boiling		26	33	49	151
Sulfuric Acid + 0.5% HCl	5	Boiling		61	49	91	434
Sulfuric Acid + 1% HCl	10	158	(70)	<1	11	24	121
Sulfuric Acid + 1% HCl	10	194	(90)	94	45	66	326
Sulfuric Acid + 1% HCl	10	Boiling		225	116	192	869
Sulfuric Acid + 2% HF	10	Boiling		29	22	26	55
Sulfuric Acid + 200 ppm Cl^-	25	158	(70)	11	12	37	110
Sulfuric Acid + 200 ppm Cl^-	25	Boiling		215	186	182	325
Sulfuric Acid + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$	11.5	Boiling		3	42	837	1815
Sulfuric Acid + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$ (ASTMG28B)	23	Boiling		8	55	2155	2721
Sulfuric Acid + 42 g/l $Fe_2(SO_4)_3$ (ASTMG28A)	50	Boiling		40	250	143	23

Average Corrosion Rate Per Year, mils** (C-22® alloy, C-276 alloy, C-4 alloy, 625 alloy)

*Average of 4-10 tests.
**To convert mils per year (mpy) to mm per year, divide by 40.

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 percent NaCl + 0.1 percent $Fe_2(SO_4)_3$+0.01 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 deg. C increments to determine the lowest temperature at which pitting corrosion initiated (observed by examination at a magnification of 40X) after a 24-hour exposure period (Critical Pitting Temperature), and the lowest temperature at which crevice corrosion initiated in a 100-hour exposure period (Critical Crevice-Corrosion Temperature).

Alloy	Critical Pitting Temperature		Critical Crevice-Corrosion Temperature	
	°C	°F	°C	°F
HASTELLOY® C-22® alloy	>150	>302	102	212 (Boiling)
HASTELLOY C-276 alloy	150	302	80	176
HASTELLOY C-4 alloy	140	284	50	122
HAYNES® 625 alloy	90	194	50	122
HASTELLOY G-30® alloy	70	158	40	104
Allegheny AL-6XN® alloy	70	158	45	113
Avesta 254 SMO® alloy	60	140	40	104
FERRALIUM® alloy 255	50	122	35	95
Alloy 904L	45	113	20	68
Type 317LM Stainless Steel	35	95	15	59
Alloy 825	25	77	≤5	≤23
Carpenter 20Cb-3® alloy	25	68	≤5	≤23
Type 316 Stainless Steel	20	68	≤5	≤23

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 percent H_2SO_4+ 1.2 percent HCl+1 percent $FeCl_3$+1 percent $CuCl_2$. 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).

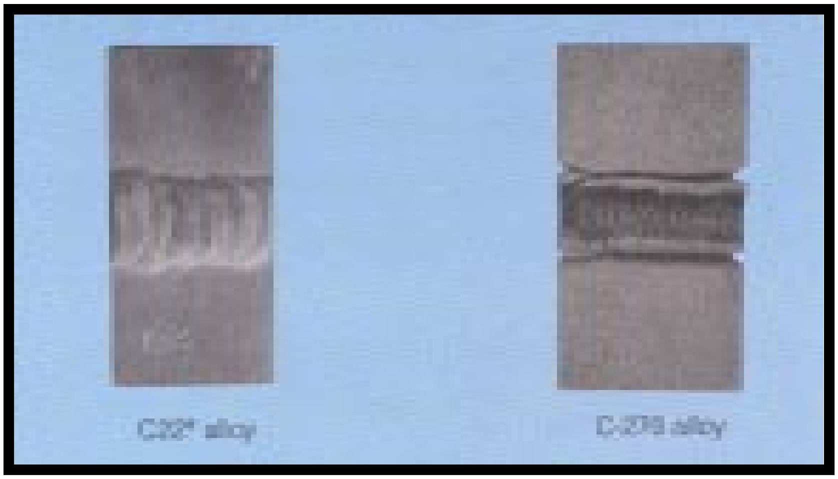
Alloy	Critical Pitting Temperature	
	°C	°F
HASTELLOY C-22 alloy	120	248
HASTELLOY C-276 alloy	110	230
HASTELLOY C-4 alloy	90	194
HAYNES 625 alloy	75	167

Stress-Corrosion Cracking Data in 20.4 Percent Magnesium Chloride for 1 Week

Condition	Test Temperature, 400°F (204°C)	Test Temperature, 450°F (232°C)	Hardness, Rockwell
Mill Annealed	No cracks	No cracks	R_B 90
20% Cold Worked	No cracks	No cracks	R_C 33
50% Cold Worked	No cracks	No cracks	R_C 43

THERMAL STABILITY

A practical concern related to an alloy's susceptibility to intergranular corrosion is the heat-affected zone of weldments. Welded test coupons of C-276 and C-22® alloys were exposed to an oxidizing sulfuric acid process solution.* C-276 alloy suffered unusually severe base metal, weld metal, and heat-affected zone attack in this particular environment. In fact only one-third of the coupon thickness in the heat-affected zone survived the corrosion test. C-276 alloy is seldom attacked to this degree in other media. There was minimal corrosion attack on the C-22 alloy sample.



*11% H_2SO_4+3.9% $Fe_2(SO_4)_3$ + other chemicals at 302°F (150°C) and overpressurized with 0_2.

Corrosion-Resistant Weld Filler Metal

Many corrosion failures are associated with welds. Reliable, cost effective and practical solutions to corrosion weld problems involve the use of HASTELLOY C-22 filler metal. Tests were conducted at the Los Alamos National Laboratory, New Mexico, in a simulated incinerator off-gas scrub solution for 39 days. Alloy 625 suffered severe base metal and weld metal attack in this particular environment. Moderate attack of the base metal was observed on AL-6XN alloy. C-22 alloy exhibited no corrosion attack of the weld metal and base metal.

3M NaCl+0.1M $FeCl_3$+0.1M NaF
167°F (75°C), pH = 1

Alloy		Corrosion Rate
Base Metal	Filler Weld	(mpy)
AL-6XN	625	112
AL-6XN	C-22	72

AL-6XN base
625 weld

AL-6XN base
C-22 weld

3M NaCl+0.1M $FeCl_3$+0.1M NaF
167°F (75°C), pH = 1

Alloy		Corrosion Rate
Base Metal	Filler Weld	(mpy)
625	625	100
625	C-22	94
C-22	C-22	0.17

625 base
625 weld

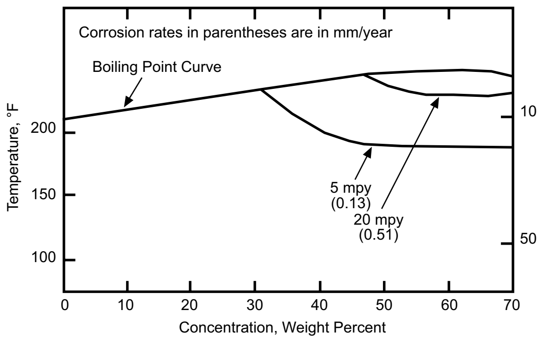
625 base
C-22 weld

C-22 base
C-22 weld

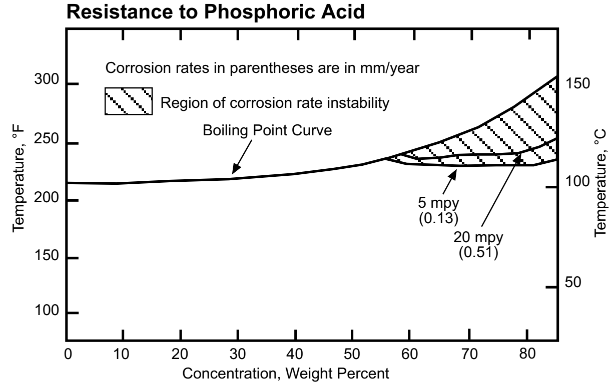
ISOCORROSION DIAGRAMS*

The isocorrosion diagrams shown on this page 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.

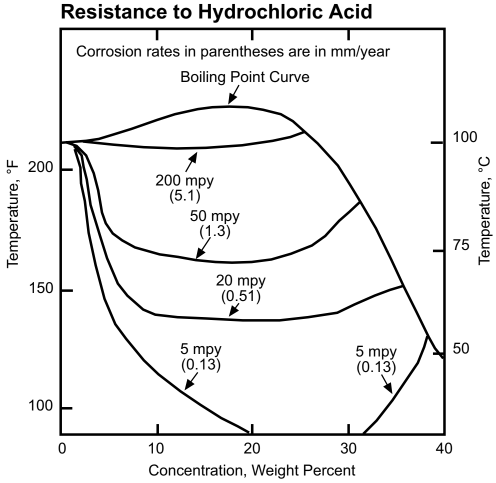
Resistance to Nitric Acid



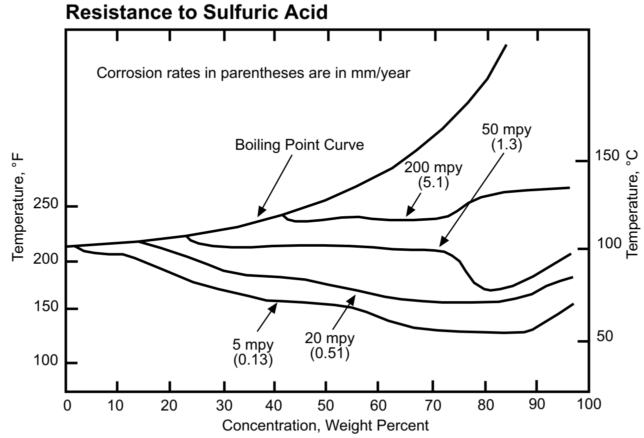
Resistance to Phosphoric Acid



Resistance to Hydrochloric Acid



Resistance to Sulfuric Acid



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

AVERAGE PHYSICAL PROPERTIES

Physical Property	Temp., °F	British Units	Temp., °C	Metric Units
Density	75	0.314 lb/in.^{3}	24	8.69 g/cm.^{3}
Melting Temperature Range	2475-2550		1357-1399	
Electrical Resistivity	75	44.8 microhm-in.	24	1.14 microhm-m
	212	48.3 microhm-in.	100	1.23 microhm-m
	392	48.7 microhm-in.	200	1.24 microhm-m
	572	49.3 microhm-in.	300	1.25 microhm-m
	752	49.6 microhm-in.	400	1.26 microhm-m
	932	49.9 microhm-in.	500	1.27 microhm-m
	1112	50.2 microhm-in.	600	1.28 microhm-m
Mean Coefficient of Thermal Expansion	75-200	6.9 microinches/in.-°F	24-93	12.4 x 10^{-6} m/m-K
	75-400	6.9 microinches/in.-°F	24-204	12.4 x 10^{-6} m/m-K
	75-600	7.0 microinches/in.-°F	24-316	12.6 x 10^{-6} m/m-K
	75-800	7.4 microinches/in.-°F	24-427	13.3 x 10^{-6} m/m-K
	75-1000	7.7 microinches/in.-°F	24-538	13.9 x 10^{-6} m/m-K
	75-1200	8.1 microinches/in.-°F	24-649	14.6 x 10^{-6} m/m-K
	75-1400	8.5 microinches/in.-°F	24-760	15.3 x 10^{-6} m/m-K
	75-1600	8.8 microinches/in.-°F	24-871	15.8 x 10^{-6} m/m-K
	75-1800	9.0 microinches/in.-°F	24-982	16.2 x 10^{-6} m/m-K
Thermal Diffusivity	70	0.004 in.^{2}/sec.	21	2.7 x 10^{-6} m^2/s
	212	0.005 in.^{2}/sec.	100	3.0 x 10^{-6} m^2/s
	392	0.005 in.^{2}/sec.	200	3.5 x 10^{-6} m^2/s
	572	0.006 in.^{2}/sec.	300	3.9 x 10^{-6} m^2/s
	752	0.007 in.^{2}/sec.	400	4.2 x 10^{-6} m^2/s
	932	0.007 in.^{2}/sec.	500	4.6 x 10^{-6} m^2/s
	1112	0.007 in.^{2}/sec.	600	4.8 x 10^{-6} m^2/s
Thermal Conductivity	118	70 Btu-in./ft.^{2} hr.-°F	48	10.1 W/m-K
	212	77 Btu-in./ft.^{2} hr.-°F	100	11.1 W/m-K
	392	93 Btu-in./ft.^{2} hr.-°F	200	13.4 W/m-K
	572	108 Btu-in./ft.^{2} hr.-°F	300	15.5 W/m-K
	752	121 Btu-in./ft.^{2} hr.-°F	400	17.5 W/m-K
	932	135 Btu-in./ft.^{2} hr.-°F	500	19.5 W/m-K
	1112	148 Btu-in./ft.^{2} hr.-°F	600	21.3 W/m-K
Specific Heat	126	0.099 Btu/lb.-°F	52	414 J/Kg-K
	212	0.101 Btu/lb.-°F	100	423 J/Kg-K
	392	0.106 Btu/lb.-°F	200	444 J/Kg-K
	572	0.110 Btu/lb.-°F	300	460 J/Kg-K
	752	0.114 Btu/lb.-°F	400	476 J/Kg-K
	932	0.116 Btu/lb.-°F	500	485 J/Kg-K
	1112	0.123 Btu/lb.-°F	600	514 J/Kg-K

Average Dynamic Modulus of Elasticity

Form	Condition	Test Temperature °F	Test Temperature (°C)	Average Dynamic Modulus of Elasticity 10^6 psi	Average Dynamic Modulus of Elasticity GPa
Plate	Heat-treated at 2050°F (1121°C) Rapid Quenched	Room		29.9	(206)
		200	(93)	29.4	(203)
		400	(204)	28.5	(196)
		600	(316)	27.6	(190)
		800	(427)	26.6	(183)
		1000	(538)	25.7	(177)
		1200	(649)	24.8	(171)
		1400	(760)	23.6	(163)
		1600	(871)	22.4	(154)
		1800	(982)	21.1	(145)

Average Room Temperature Hardness

Form	Hardness, Rockwell
Sheet	R_B 93
Plate	R_B 95

Average Impact Strength, Plate*

Condition	V-Notch Impact Strength, Room Temperature ft.-lb.	Room Temperature Joules	-320°F (-196°C) ft.-lb.	-320°F (-196°C) Joules
Heat-treated at 2050°F (1121°C) Rapid Quenched	260*	353*	259*	351*
Aged 100 hrs. at 500°F (260°C)	-	-	259*	351*
Aged 100 hrs. at 1000°F (538°C)	-	-	259*	351*
Aged 100 hrs. at 1000°F (538°C)	-	-	87	118

*Specimens did not break.

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. (50.8 mm), %
Sheet,	Room		116	59	57
0.028 - 0.125 in.	200	(93)	110	54	58
(0.71 - 3.2 mm)	400	(204)	102	44	57
thick**	600	(316)	98	42	62
	800	(427)	95	41	67
	1000	(538)	91	40	61
	1200	(649)	85	36	65
	1400	(760)	76	35	63
Plate,	Room		114	54	62
1/4 - 3/4 in.	200	(93)	107	49	65
(6.4 - 19.1 mm)	400	(204)	98	41	66
thick***	600	(316)	95	36	68
	800	(427)	92	35	68
	1000	(538)	88	34	67
	1200	(649)	83	32	69
	1400	(760)	76	31	68
Bar,	Room		111	52	70
1/2 - 2 in.	200	(93)	105	45	73
(12.7 - 50.8 mm)	400	(204)	96	38	74
diameter***	600	(316)	92	34	79
	800	(427)	89	31	79
	1000	(538)	84	29	80
	1200	(649)	80	28	80
	1400	(760)	72	29	77

* Ksi can be converted to MPa (megapascals) by multiplying by 6.895.
** Average of 10-20 tests. *** Average of 16-32 tests. **** Average of 8-16 tests.

FABRICATION

Heat Treatment
Wrought forms of HASTELLOY® C-22® alloy are furnished in the solution heat-treated condition unless otherwise specified. The standard solution heat treatment consists of heating at 2050°F (1121°C) followed by rapid air cooling or water quenching.

Parts which have been hot formed or severely cold formed should be solution heat-treated prior to further fabrication or installation.

Forming
C-22 alloy has excellent forming characteristics. Cold forming is the preferred method of forming. Because of its good ductility, it can easily be cold-worked. The alloy is generally stiffer than the austenitic stainless steels. Therefore, more energy is required during cold forming. For further information, please consult the Haynes publication H-2010.

Formability

Form	Condition	HASTELLOY Alloys	Average Olsen Cup Depth in.	Average Olsen Cup Depth mm
Sheet, 0.028 in. (0.71 mm) thick	Heat-treated at 2050°F (1121°C), Rapid Quenched	C-22	0.49	12.4
		C-276	0.48	12.2
Sheet, 0.028 in. (0.71 mm) thick	Aged at 1600°F (871°C), for 1000 hrs.	C-22	0.49	12.4
		C-276	0.48	12.2
Sheet, 0.028 in. (0.71 mm) thick	Cold Worked 33%	C-22	0.49	12.4
		C-276	0.48	12.2
Sheet, 0.028 in. (0.71 mm) thick	Cold Worked 33% and Aged at 932°F (500°C) for 100 hrs.	C-22	0.49	12.4
		C-276	0.48	12.2

Average Room Temperature Tensile Data, Cold-Worked Sheet

Cold Worked %	Ultimate Tensile Strength, Ksi*	Yield Strength at 0.2% Offset, Ksi*	Elongation in 2 in. (50.8 mm), %
0	116	59	57
10	130	93	39
20	151	127	23
30	170	151	13
40	192	174	9
50	206	183	10
60	222	202	7

Average Room Temperature Tensile Data, Cold-Worked and Aged** Sheet

Cold Worked %	Ultimate Tensile Strength, Ksi*	Yield Strength at 0.2% Offset, Ksi*	Elongation in 2 in. (50.8 mm), %
0	116	62	73
10	141	110	42
20	165	141	28
40	206	193	15
60	250	244	6

* Ksi can be converted to MPa (megapascals) by multiplying by 6.895.
** Aged 100 hours at 932°F (500°C).

Average Room Temperature Hardness, Aged Sheet*

Aging Temperature, °F	(°C)	Cold Reduction, % 0	10	20	30	40	50	60
No Aging		R_B 90	R_C 24	R_C 33	R_C 36	R_C 40	R_C 41	R_C 43
940	(504)	R_B 94	R_C 24	R_C 32	R_C 37	R_C 42	R_C 45	R_C 48
1010	(543)	R_B 95	R_C 26	R_C 32	R_C 41	R_C 44	R_C 45	R_C 48
1070	(577)	R_B 95	R_C 28	R_C 32	R_C 39	R_C 40	R_C 44	R_C 48
1130	(610)	R_B 93	R_C 22	R_C 27	R_C 33	R_C 37	R_C 41	R_C 45
1200	(649)	R_B 93	R_C 21	R_C 27	R_C 33	R_C 37	R_C 41	R_C 45
1260	(682)	R_B 95	R_C 20	R_C 25	R_C 31	R_C 36	R_C 41	R_C 44
1510	(821)	R_B 94	R_C 21	R_C 26	R_C 32	R_C 35	R_C 36	R_C 37
1770	(966)	R_B 93	R_C 21	R_C 21	R_C 21	R_C 23	R_C 25	R_C 25
1980	(1082)	R_B 83	R_B 83	R_B 84	R_B 84	R_B 83	R_B 83	R_B 80

*Aged 100 hours.

Average Impact Strength, Aged Plate

Aging Temperature, °F	(°C)	Aging Time, hrs.	V-Notch Impact Strength -320°F (-196°C) ft.-lb.	Joules
1000	(538)	1	259*	351*
		10	259*	351*
		100	259*	351*
1200	(649)	1	259*	351*
		10	259*	351*
		100	99	134
1400	(760)	1	259*	351*
		10	84	114
		100	28	38
1600	(871)	1	118	160
		10	38	52
		100	3	4
1800	(982)	1	114	155
		10	44	60
		100	12	16

*Specimens did not break.

WELDING

HASTELLOY® C-22® alloy is readily welded by gas tungsten arc (GTAW), gas metal arc (GMAW), and shielded metal arc (SMAW) welding techniques. Its welding characteristics are similar to those for HASTELLOY C-276 and C-4 alloys. Submerged arc welding is not recommended as this process is characterized by high heat input to the base metal and slow cooling of the weld.

Base Metal Preparation
The joint surface and adjacent area should be thoroughly cleaned before welding. All grease, oil, crayon marks, sulfur compounds, and other foreign matter should be removed.

Filler Metal Selections
Matching composition filler metal is recommended for joining C-22 alloy. For gas-tungsten-arc and gas-metal-arc welding, C-22 filler wire (ER NiCrMo-10) is recommended. For shielded metal arc welding, C-22 covered electrodes (ENiCrMo-10; UNS W86022) are recommended.

Detailed fabricating information for C-22 alloy is available in the booklet, Fabrication of HASTELLOY® Corrosion-Resistant Alloys (H-2010) and C-22® Alloy Welding Information (H-2066).

Average Transverse Tensile Data, Weldments*

Form		Test Temperature °F	°C	Ultimate Tensile Strength, Ksi**	Yield Strength at 0.2% Offset, Ksi**	Elongation in 2 in. (50.8 mm), %
Sheet, 0.125 in. (3.2 mm) thick	GTAW	Room		108	61	30
		1000	(538)	79	40	23
Plate, 1/4 in. (6.4 mm) thick	GTAW	Room		116	56	60
		1000	(538)	88	36	51
	GMAW (short arc)	Room		111	57	43
		1000	(538)	85	39	46
Plate, 1/2 in. (12.7 mm) thick	GTAW	Room		114	65	47
		1000	(538)	86	45	52
		1400	(760)	71	39	30
	GMAW (short arc)	Room		109	63	38
		1000	(538)	82	45	38
		1400	(760)	63	39	25
	GMAW (spray)	Room		110	67	37
		1000	(538)	80	45	33
		1400	(760)	68	41	27
Plate, 3/4 in. (19.1 mm) thick	SMAW	Room		111	56	58
Plate, 1.0 in. (23.4 mm) thick	GTAW (short arc)	Room		106	54	44
		752	(400)	92	38	48
	GMAW (spray)	Room		109	56	51
		752	(400)	93	35	59
Plate, 1.5 in. (46.1 mm) thick	GMAW (short arc)	Room		109	56	54
		752	(400)	92	38	59

*Average of 3-9 tests. ** Ksi can be converted to MPa (megapascals) by multiplying by 6.895.

Average Tensile Data, All-Weld Metal*

Weld Type	Test Temperature °F	Test Temperature °C	Ultimate Tensile Strength, Ksi**	Yield Strength at 0.2% Offset, Ksi**	Elongation in 2 in. (50.8 mm), %
GTAW	Room		113	76	47
	500	(260)	94	60	52
	1000	(538)	187	57	51
GMAW (short arc)	Room		113	72	52
	500	(260)	94	60	52
	1000	(538)	84	54	55
SMAW	Room		110	74	47
	752	(400)	87	56	49

*Average of 10-20 tests. **Ksi can be converted to MPa (megapascals) by multiplying by 6.895.

Average Impact Strength, Weldments

Condition		V-Notch* Impact Strength, Room Temperature ft.-lb.	Room Temperature Joules	-320°F (-196°C) ft.-lb.	-320°F (-196°C) Joules
Plate, 1/2 in. (12.7 mm) thick	GTAW	148	201	111	150
	GMAW (short arc)	135	183	97	131
	GMAW (spray)	144	195	118	160
Plate, 3/4 in. (19.1 mm) thick	GTAW	148	201	118	160
	GMAW (short arc)	121	164	115	156
	GMAW (spray)	149	202	102	138
	SMAW	76	103	53	72

*Notch was located in the center of the weldment on the transverse edge.

Typical Bend Test Data, Welded Plate*

Weld Type	Face Bend, 2T	Side Bend 2T	Side Bend 1 1/2T	Root Bend, 2T
GTAW	Passed	Passed	Passed	Passed
GMAW (short arc)	Passed	Passed	Passed	Passed
GMAW (spray)	Passed	Passed	Passed	Passed
SMAW	Passed	Passed	-	Passed

*Duplicate specimens, 1/2 in. (12.7 mm) thick. Tested using AWS Specification 5.11 as a guide.

Room Temperature Tensile Data of Weldments After Thermal Aging

Welding Method	Condition	Specimen	Ultimate Tensile Strength, Ksi*	Yield Strength at 0.2% Offset, Ksi*	Elongation in 2 in. (50.8mm), %
GTAW	As Welded	Unnotched	114	58	60
	Aged 4000 hrs. at 842°F (450°C)	Unnotched	114	59	60
	As Welded	Notched	147	84	-
	Aged 4000 hrs. at 842°F (450°C)	Notched	152	85	-
GMAW	As Welded	Unnotched	106	54	44
	Aged 4000 hrs. at 842°F (450°C)	Unnotched	110	55	58
	As Welded	Notched	146	82	-
	Aged 4000 hrs. at 842°F (450°C)	Notched	150	86	-

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

Average Impact Strength, Weldments

		V-Notch Impact Strength			
		Room Temperature		-320°F (-196°C)	
Method	Condition	ft.-lb.	Joules	ft.-lb.	Joules
GTAW	As Welded	148	201	118	160
	Aged 4000 hrs. at 842°F (450°C)	124	168	-	-
GMAW	As Welded	144	195	106	144
	Aged 4000 hrs. at 842°F (450°C)	124	168	106	144

Dissimilar Weldment Mechanical Data, All-Weld Metal, Room Temperature

Weld Type	Base Metal	Weld Metal	Ultimate Tensile Strength, Ksi*	Yield Strength at 0.2% Offset, Ksi*	Elongation in 2 in. (50.8mm), %	V-Notch Impact Strength ft.-lb.
GTAW	316L	C-22	115	84	40	121
SMAW	316L	C-22	113	73	41	58
GTAW	904L	C-22	113	74	44	136
SMAW	904L	C-22	110	72	44	61
GTAW	C-22	C-22	113	76	47	148
SMAW	C-22	C-22	113	71	43	60

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

MACHINING

The following are guidelines for performing typical machining operations upon C-22® alloy wrought stock. Exact details for specific machining jobs will vary with circumstances of the particular job. Other tool materials not listed here may be suitable for machining C-22 alloy under various conditions. For further information, please consult Haynes publication H-2010.

Recommended Tool Types and Machining Conditions

Operations	Carbide Tools	High Speed Steel Tools
Drilling	C-2 grade not recommended, but tipped drills may be successful on rigid setup of no great depth. The web must be thinned to reduce thrust Use 135° included angle on point, Gun drill can be used. Speed: 50 sfm. Oil[2] or water-base[3] coolant. Coolant-feed carbide tipped drills may be economical in some setups.	M-33, M-40 series[1] or T-15: Use short drills, heavy web, 135° crank-shaft, grind points wherever possible. Speed: 10-15 sfm. Feed: 0.001 in. rev. 1/8 in. dia. 0.002 in. rev. 1/4 in. dia. 0.003 in. rev. 1/2 in. dia. 0.005 in. rev. 3/4 in. dia. 0.007 in. rev. 1 in. dia. Oil or water-base coolant. Use coolant feed drills if possible.
Normal Roughing; Turning or Facing	C-2 or C-3 grade: Negative rake square insert, 45° SCEA[4], 1/32 in. nose radius. Tool holder: 5° neg. back rake, 5° neg. side rake. Speed: 90 sfm depending on rigidity of set up, 0.010 in. feed, 0.150 in. depth of cut. Dry[5], oil, or water-base coolant.	
Finishing; Turning or Facing	C-2 or C-3 grade: Positive rake square insert, if possible, 45° SCEA, 1/32 in. nose radius. Tool holder: 5° pos. back rake, 5° pos. side rake. Speed: 95-110 sfm, 0.005-0.007 in. feed, 0.040 in. depth of cut. Dry or water-base coolant.	

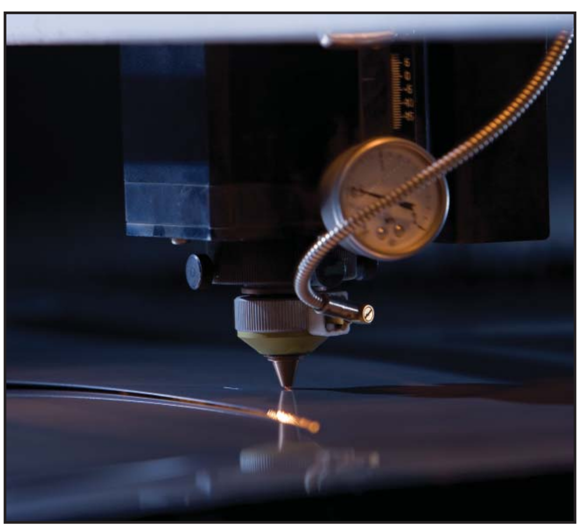
NOTES:
1. M-40 series High Speed Steels include M-41, M-42, M-43, M-44, M-45 and M-46 at the time of writing. Others may be added and should be equally suitable.
2. Oil coolant should be a premium quality, sulfochlorinated oil with extreme pressure additives. A viscosity at 100°F from 50 to 125 SSU.
3. Water-base coolant should be premium quality, sulfochlorinated water soluble oil or chemical emulsion with extreme pressure additives. Dilute with water to make 15:1 mix. Water-base coolant may cause chipping and rapid failure of carbide tools in interrupted cuts.
4. SCEA - Side cutting edge angle or lead angle of the tool.
5. At any point where dry cutting is recommended, an air jet directed on the tool may provide substantial tool life increase. A water-base coolant mist may also be effective.

SERVICE CENTER INFORMATION

Service and Availability are Standard at Haynes International.

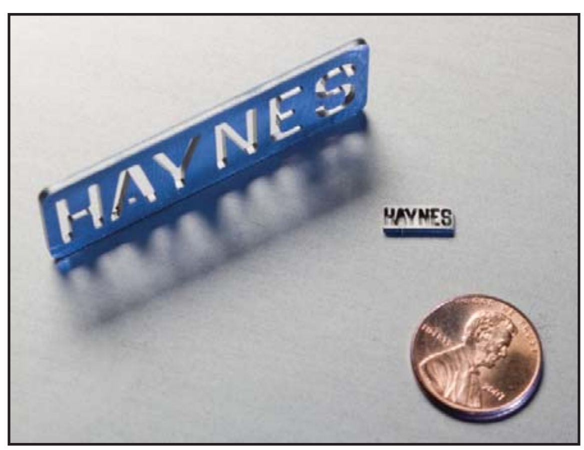
Our global service centers stock millions of pounds of high-performance corrosion-resistant and high-temperature alloys. Whether you need on-demand delivery of finished goods, end-use technical support or a partner with global presence, Haynes International provides value far beyond the alloys themselves.

Corrosion-resistant and high-temperature alloy plate is stocked in several of our global service centers and ready for immediate delivery.



Our state-of-the art laser is one of many of our specialized equipment that provides precision detail.

Our LaserQC® equipment accurately maps out parts for duplication.



Value-added services such as near-net shaped and laser-cut parts can be cut in various sizes to specific drawings and specifications to reduce your labor time and material waste.

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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