HAYNES® HR-160® alloy

Principal Features

Resistance to High-Temperature Corrosion

HAYNES® HR-160® (UNS N12160) alloy is a solid-solution-strengthened nickel-cobalt-chromium-silicon alloy with outstanding resistance to various forms of hightemperature corrosion attack. HR-160® alloy has excellent resistance to sulfidation and chloride attack in both reducing and oxidizing atmospheres. The alloy also has exceptionally good resistance to oxidation, hot corrosion, carburization, metal dusting, nitridation, and corrosion attack by low melting point compounds such as those formed by phosphorus, vanadium, and other impurities. The alloy is especially suited for applications in high temperature corrosive environments generatedby combustion of low grade fuels or processing of chemical feedstocks with corrosive contaminants such as sulfur, chlorine, fluorine, vanadium, phosphorus, and others. The alloy is capable of withstanding temperatures up to 2200°F (1204°C).

Ease of Fabrication

HAYNES® HR-160® alloy has excellent forming and welding characteristics. It may be forged or otherwise hot-worked, providing it is held at 2050°F (1121°C) for time sufficient to bring the entire piece to temperature. As a consequence of its good ductility, HR-160® alloy is also readily formed by cold working. Cold- or hot-worked parts should be annealed and rapidly cooled in order to restore the best balance of properties. HR-160® alloy can be welded by a variety of techniques, including gas tungsten arc (TIG), gas metal arc (MIG), and resistance welding.

Heat Treatment

HR-160® alloy is furnished in the solution annealed condition, unless otherwise specified. The alloy is solution annealed at 2050°F (1121°C) and rapidly cooled for optimum properties. Intermediate annealing, if required during fabrication and forming operations, can be performed at temperatures as low as 1950°F (1066°C). HR-160® alloy is furnished in the solution annealed condition, unless otherwise specified.

Applicable Specifications

HR-160® alloy plate, sheet, strip, bar, forging, tubing, pipe, and fittings are covered by ASME specifications SB 366, SB 435, SB 572, SB 619, SB 622, and SB 626 and ASTM specifications B 366, B 435, B 572, B 619, B 622, and B626.

ASME Vessel Code

HR-160® is covered in ASME Section VIII Division 1 for construction up to 1500°F (815°C). Code Case 2385 covers HR-160® for construction up to 1800°F (982°C). The thickness of the plate at welded joints is limited to 0.50 inches.

Applications

Cross-section of HR-160® flue-gas stack annubar flow monitoring device for waste incineration and chemical process industries.

Lining (inner cylinder) of exhaust ducting in pulp and paper recovery boiler made from HR-160® alloy. Outer shell is carbon steel.

Many waste incineration and chemical process facilities have used HR-160® thermocouple protection tubes with outstanding success. Life extensions greater than 10x compared to Ni-Cr alloys and stainless steels are common.

HR-160® tube shields are considered the premier superheater tube shield material for municipal and industrial waste incineration systems. The use of HR-160® alloy has resulted in greatly improved life in municipal waste incinerators where high temperature corrosion and fly ash erosion are major considerations.

Nominal Composition

Weight %

Nickel:	37 Balance
Cobalt:	29
Chromium:	28
Iron:	2 max.
Silicon:	2.75
Manganese:	0.5
Titanium:	0.5
Carbon:	0.05
Tungsten:	1 max.
Molybdenum:	1 max.
Columbium:	1 max.
Aluminum:	0.4 max.

High-temperature Corrosion Resistance

Sulfidation in Reducing Atmospheres

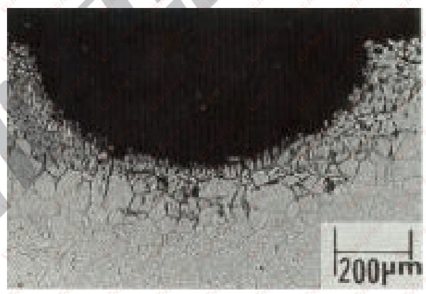
Ar - 5%H_2 - 5%CO - 1%CO_2 - 0.15%H_2S (Vol. %)

(PO_2 = 3 x 10^{-19} atm, PS_2 = 0.9 x 10^{-6} atm)

1600°F (871°C) / 215 hours

HR-160® alloy

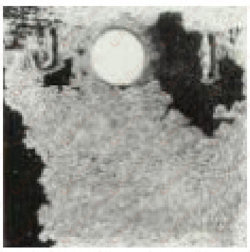
556® alloy



Alloy 800H

Top edge of the photograph represents the original sample surface. The specimens were tested and then cathodically descaled to remove the corrosion products prior to mounting for metallography.

1600°F (871°C) / 500 hours



HR-160® alloy

RA330 alloy

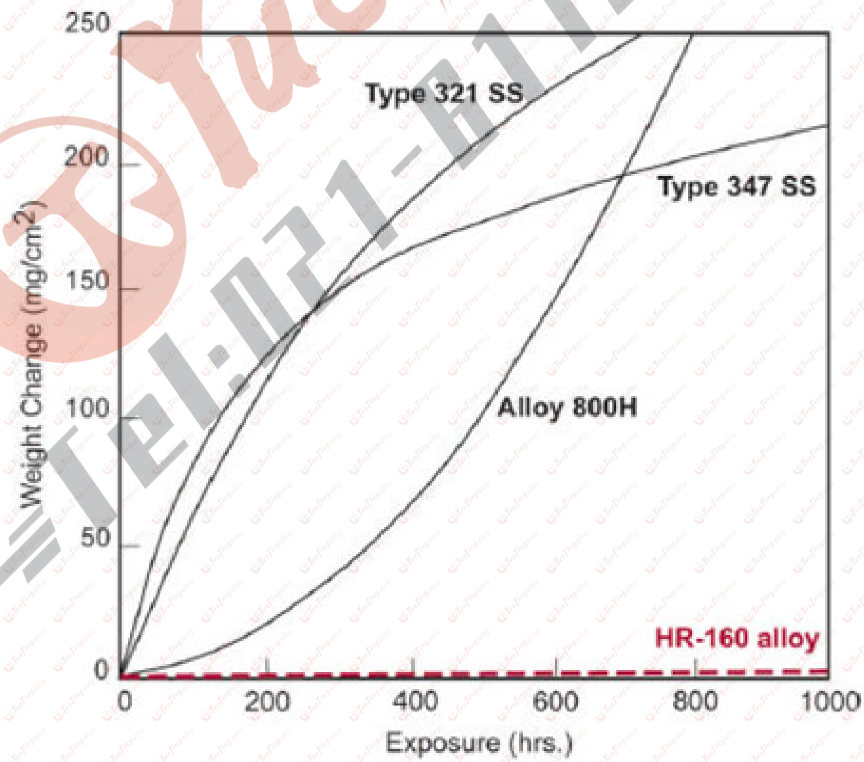
High-temperature Corrosion Resistance Continued

1600°F (871°C)/500 hours							
Alloy	Cobalt	Metal Loss		Average Depth of Attack		Maximum Depth of Attack	
-	%	Mils	mm	Mils	mm	Mils	mm
6B	57	0.3	0.008	3.1	0.08	3.3	0.08
HR-160®	**30**	**0.2**	**0.005**	**4.7**	**0.12**	**5.2**	**0.13**
25	51	4.1	0.1	8.4	0.21	14.6	0.37
188	39	7.6	0.1	14.9	0.38	23.6	0.6
150	50	10.3	0.26	22.1	0.56	28.3	0.72
556®	18	20.6	0.52	31.9	0.81	35.6	0.9

Sulfidation in Reducing Atmospheres

H-46%CO-0.8%CO-1.7%HS Total Depth Attack				
Alloy	1100°F (593°C)		1300°F (704°C)	
-	mpy	mm/y	mpy	mm/y
HR-160®	**14.4**	**0.37**	**27.3**	**0.7**
6B	23.6	0.6	264.4	6.72
150	37.7	0.96	108.8	2.76
25	94.1	2.39	188.5	4.79
188	150.5	3.82	292.6	7.43
556®	121.1	3.08	345.8	8.78

H_2-7%CO-1.5%H_2O-0.6%H_2S
(PO_2= 1 x 10^{-23} atm, PS_2 = 1 x 10^{-9} atm, a_C = 0.3-0.4 at 1292°F (700°C))



Note: HR-160® alloy exhibited about 1.0 mg/cm² of weight gain after 1000 hours of exposure.

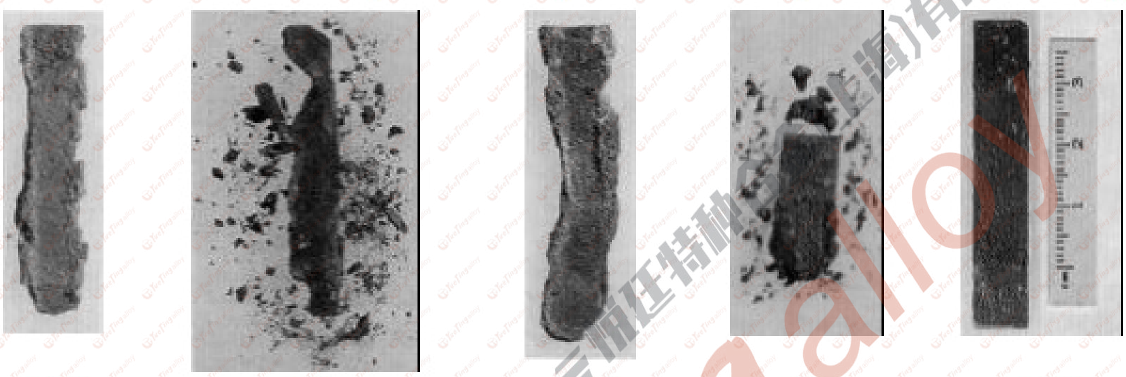
High-temperature Corrosion Resistance Continued

Sulfate-Induced Sulfidation in Combustion Atmospheres

Laboratory Hot Corrosion Burner Rig Testing - Specimens were exposed to a combustion stream generated in a burner rig fired with No. 2 fuel oil with a constant injection of 50 ppm (by weight) salt (mostly sodium chloride) into the combustion stream. Specimens were also subjected to thermal cycling by cycling them out of the test chamber once every hour and rapid fan cooling to less than 390°F (199°C) for two minutes.

No. 2 fuel oil with 0.4% sulfur
1650°F (899°C)

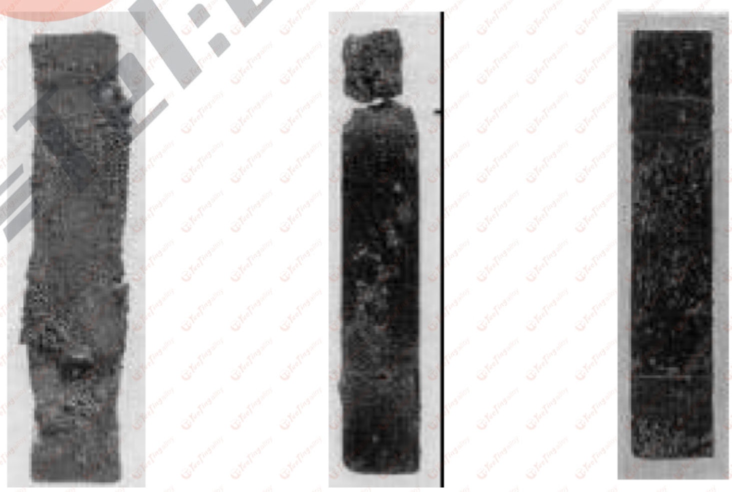
310SS | RA330 alloy | alloy 800H | alloy 625 | HR-160® alloy



1000 hours | 476 hours | 1000 hours | 940 hours | 1000 hours

253 MA® alloy | RA330 alloy | RA85H® alloy

Alloy 800H | 556® alloy | HR-160® alloy



Oxidation Resistance

Oxidation in Air

Laboratory tests were conducted in flowing air at 1800 to 2200°F (982 to 1204°C) for 1008 hours, with specimens cycled to room temperature once every 168 hours.

Alloy	1800°F (982°C)				2000°F (1093°C)				2100°F (1149°C)				2200°F (1204°C)			
	Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected	
	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm
HR-160®	**0.7**	**18**	**5.5**	**140**	**1.7**	**43**	**10.3**	**262**	**2.5**	**64**	**16.0**	**406**	**3.6**	**91**	**22.0**	**559**
800HT	0.0	0	4.1	104	7.6	193	11.6	295	11.0	279	15.0	381	19.4	493	>58	>1473
253MA	1.3	33	3.0	76	0.7	18	8.2	208	8.7	221	16.5	419	18.6	472	29.2	742
RA85H	0.5	13	8.2	208	2.9	74	25.9	658	3.7	94	>59	>1499	3.9	99	>59	>1499

Long-Term Oxidation in Air

Laboratory tests were conducted at 2000°F (1093°C) in still air (box furnace), with specimens being cycled to room temperature once every 30 days.

Alloy	1800°F (982°C)				2000°F (1093°C)				2100°F (1149°C)				2200°F (1204°C)			
	Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected	
	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm
HR-160®	**2.5**	**64**	**16.7**	**424**	**3.6**	**91**	**29.0**	**737**	**7.6**	**193**	**58.7**	**1491**	**16.7**	**4204**	**26.3**	**668**
601	0.5	13	22.4	569	5.4	137	45.1	1146	12.6	320	72.8	1849	27.3	693	38.9	988
RA85H	6.3	160	53.7	1364	17.9	455	80.3	2040	20.0	508	94.8	2408	>251.7	>6393	>251.7	>6393
800HT	20.7	526	79.8	2027	44.3	1125	51.0	1295	65.2	1656	70.3	1786	>249.9	>6373	>249.9	>6373

Plate exposed for 360 days (8,640 hours) in still air, except for 1800°F test, which was exposed for 720 days (17,280 hours). Cycled once per month.

Alloy	1800°F (982°C)				2000°F (1093°C)				2100°F (1149°C)				2200°F (1204°C)			
	Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected	
	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm
HR-160®	**1.2**	**30**	**12.0**	**305**	**2.7**	**69**	**27.9**	**709**	**5.3**	**135**	**44.6**	**1133**	**8.9**	**226**	**>250.0**	**>6350**
601	0.0	0	2.6	66	3.4	86	10.5	267	5.3	135	14.6	371	10.3	262	23.9	607
RA85H	0.7	18	14.6	371	8.9	226	14.3	363	6.4	163	>250.0	>6350	8.4	213	>250.0	>6350
800HT	4.6	117	14.1	358	22.2	564	27.9	709	43.9	1115	48.9	1242	65.6	1666	>250.0	>6350

Plate exposed for 360 days (8,640 hours) in still air. Cycled once every two months.

Chloridation Resistance

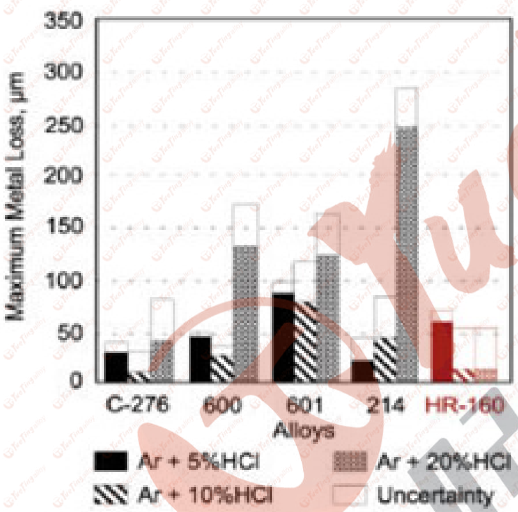
High Temperature Chloride Vapor Corrosion
Ar-20%O_2-2%H_2O-0.05%NaCl (Vol.%) 1830°F (999°C) for 75 hours

Alloy	Total Depth Of Attack	
	mils	mm
214®	11.5	0.29
HR-160®	12	0.31
800H	>62.0 (complete penetration)	

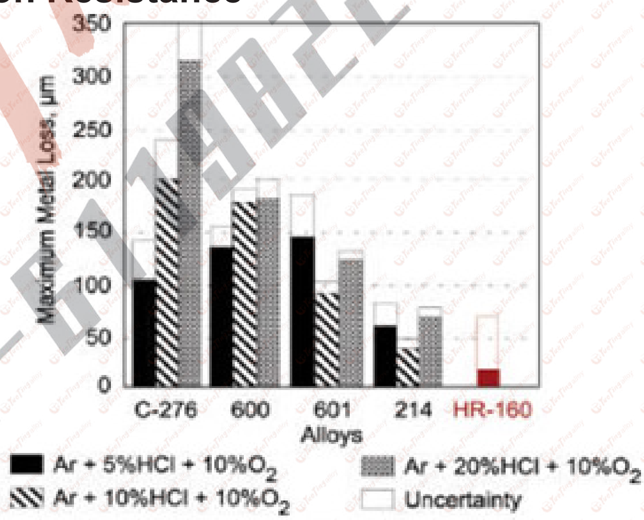
Exposure to Chloride Vapors at 1600°F (871°C)

Field tests were conducted by exposing specimens to air containing vapors of sodium chloride, potassium chloride and barium chloride at 1600°F (871°C) for 173 hours.

Chlorination Resistance



Maximal loss of sound metal per side. Laboratory tests in chlorinating atmospheres at 1112°F (600°C) for 500 hours.*



Maximal loss of sound metal per side. Laboratory tests in oxychlorinating atmospheres at 1112°F (600°C) for 500 hours.*

*Data from "Corrosion Studies and Recommendation of Alloys for an Incinerator of Glove-Boxes Wastes" by F. Devisme and N. H. Garnier, Presented at the 11th International Incineration Conference 1992, May 11-15, 1992, Albuquerque, New Mexico

Carburization Resistance

Laboratory pack carburization testing in graphite at 1800°F (982°C) for 500 hours

Alloy	Carbon Absorption (mg/cm²)	Total Depth Of Attack	
		mils	mm
HR-120®	0	0	-
556®	0	0	-
HR-160®	0.3	0	-
800HT	0.3	0.9	0.02
601	1	0.46	18
RA330®	1.9	1.79	70.6
310SS	7.7	2.14	84.2
253 MA	11.6	2.34	92.1

Exposure to Carbon Bed at 1650°F (899°C)

Field tests conducted in a carbon bed
during manufacturing of activated carbon
at 1650°F (899°C) for 120 hours

HR-160® alloy

Type 316 SS

Ar-5%H-1%CH (Vol.%) 1800°F (982°C) for 55 hours

Alloy	Carbon Absorption (mg/cm)
HR-160®	2.9
601	3.2
800H	3.6
600	7.3
HR-120®	7.9
556®	7.9
RA330®	9.2
253 MA	9.4
310SS	10.0

Nitridation Resistance

HAYNES® HR-160® alloy is also very resistant to nitridation attack. Tests were performed in flowing ammonia or nitrogen at various temperatures for 168 hours. Nitrogen absorption was determined by chemical analysis of samples before and after exposure and knowledge of the exposed specimen area.

Ammonia (NH_3) 168 hours. Nitrogen Absorption (mg/cm^2)

Alloy	1200°F (649°C)	1800°F (982°C)	2000°F (1093°C)
HR-160®	**0.9**	**2.2**	**3**
601	1.1	1.2	2.6
RA330 ®	4.7	3.9	3.1
800H	4.3	4.0	5.5
304SS	9.8	7.3	3.5
316SS	6.9	6.0	3.3
310SS	7.4	7.7	9.5
446SS	28.8	12.9	4.5
253 MA	-	3.3	6.3

Nitrogen (N_2) 2000°F (1093°C), 168 hours

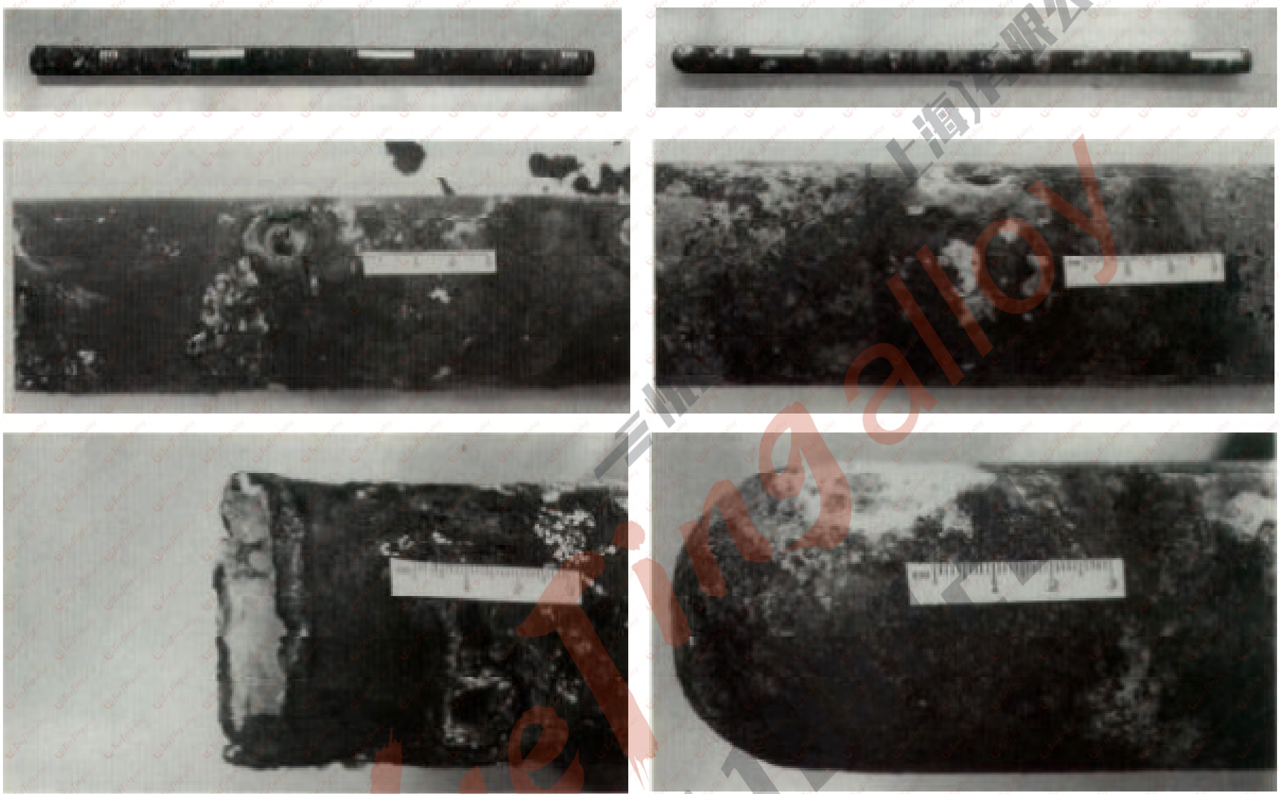
Alloy	Nitrogen Absorptions (mg/cm^2)
HR-160®	**3.9**
601	7.2
RA330®	6.6
RA85H	8.5
253 MA	10.0
800H	10.3
800HT	11.4
310SS	12.3

Waste Incineration Environments

Incineration of municipal, industrial and hazardous wastes generates very corrosive environments which typically contain such corrosive constituents as SO_2, HCl and sometimes HF, along with vapors/deposits of chlorides and sulfates. The following examples demonstrate the relative improvements resulting from upgrading to HR-160® alloy.

Soot blowers in a municipal waste incinerator
1400°F (760°C) for 75 days

Type 446 SS | **HR-160® alloy**

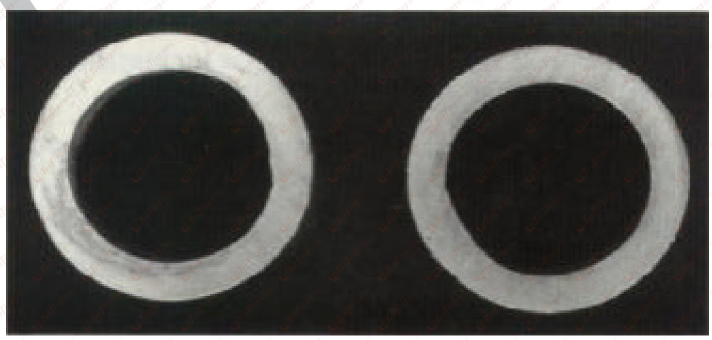


Thermowell in municipal waste incinerator
1800-2100°F (982-1149°C) for 180 days

HR-160® alloy

HAYNES® HR-160® thermowell in a municipal waste incinerator for 170 days at 1850-1950°F (1010-1066°C)

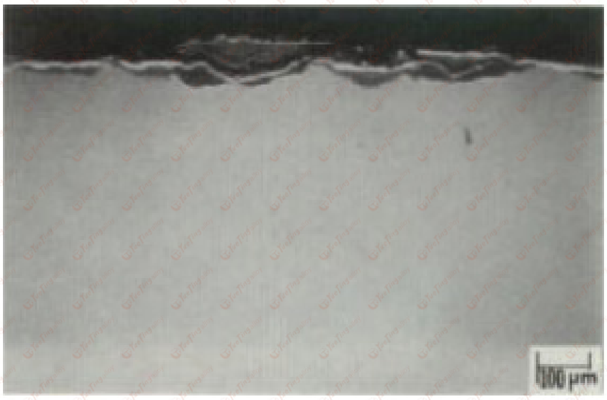
Unexposed end | Exposed end



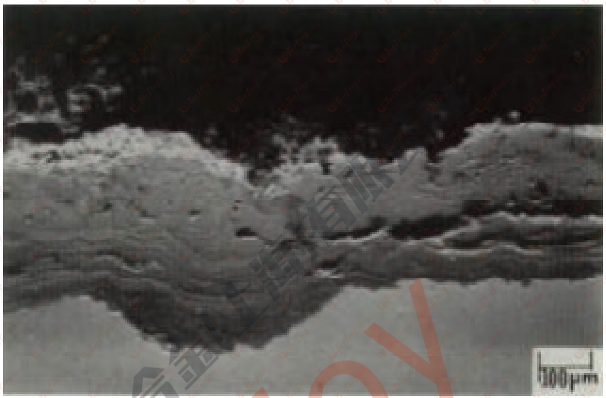
Waste Incineration Environments Continued

Field testing in a chemical waste incinerator showed little scaling or metal wastage for HR-160® alloy when exposed to the flue gas stream which contained SO_2, HCl and HF for 5800 hours at 900°F(482°C).

HR-160® alloy



alloy 600



Tensile Properties

Tensile Data (plate)*

Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	ksi	MPa	ksi	MPa	%	%
70	21	45.6	314	111.2	767	68	73
200	93	40.4	279	104	717	69	74
400	204	33.8	233	97.9	675	71	74
600	316	27.6	190	91.9	634	74	70
800	427	26	179	87.7	605	76	68
1000	538	25.5	176	81.8	564	76	69
1200	649	25.7	177	75.8	523	70	67
1400	760	24.7	170	62.1	428	73	64
1600	871	22.1	152	38.3	264	85	84
1800	982	10.8	74	20.4	140	90	98
2000	1093	5	34	10.8	74	88	98
2100	1149	2.3	16	6	41	113	94
2200	1204	1.6	11	4.4	30	110	94

*Hot-Rolled and Solution-Annealed

Tensile Properties Continued

Tensile Data (Sheet)*

Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
70	21	51.2	353	110	758	63
1000	538	32.7	225	82.5	569	73
1200	649	31.2	215	75.3	519	62
1400	760	30.7	212	61.1	421	47
1600	871	15.9	110	34.9	241	41
1800	982	9.5	66	18.7	129	51
2000	1093	4.7	32	9.8	68	53
2100	1149	2.8	19	6.6	46	107
2200	1204	2	14	4.8	33	91

*Solution-Annealed

Creep and Stress Rupture Strengths

Plate- 2050°F (1121°C) Solution Anneal

Test Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in:							
			100 h		1000 h		10,000 h		100,000 h	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1100	593	1	29.4	203	20.4	141	14.4*	100	-	-
-	-	Rupture	45.5	315	32.2	223	22.9	158	113	16.3
1200	649	1	18.9	131	12.1	91	9.3*	64	-	-
-	-	Rupture	32.2	223	22.4	154	15.6	108	76	11
1300	704	1	12.5	86	8.7	60	6.2*	43	-	-
-	-	Rupture	22.9	158	15.7	108	10.8	75	51	7.4
1400	760	1	8.5	59	6	41	4.2*	29	-	-
-	-	Rupture	16.4	113	11	76	7.4	51	34	5
1500	816	1	5.9	41	4.1	28	2.9*	20	-	-
-	-	Rupture	11.7	81	7.7	53	5.1	35	23	3.4
1600	871	1	4.2	29	2.9	20	2.1*	14	-	-
-	-	Rupture	8.4	58	5.5	38	3.6	25	17	2.4
1700	927	1	3	21	2.1	14	1.5*	10	-	-
-	-	Rupture	6.1	42	3.9	27	2.5	17	11	1.6
1800	982	1	2.2	15	1.5	10	1.1*	8	-	-
-	-	Rupture	4.4	30	2.8	19	1.8	12	8	1.2

*Extrapolation

Creep and Stress Rupture Strengths Continued

Sheet, Solution-annealed

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in			
			100 h		1,000 h	
°F	°C	%	ksi	MPa	ksi	MPa
1200	649	0.5	16	110	12.5	86
		1	18.5	128	15	103
		R	28	193	20	138
1300†	704	0.5	11.5	79	9.2	63
		1	13.9	96	10.8	74
		R	19	131	14.5	100
1400	760	0.5	8.5	59	6.8*	47*
		1	9.9	68	8.2*	57*
		R	13	90	9.9	68
1500	816	0.5	6.2	43	4.9*	34*
		1	8.2	57	6.0*	41*
		R	9.6	66	7.9	54
1600	871	0.5	4.7	32	3.4*	23*
		1	5.2	36	4.3*	30*
		R	6.8	47	5.1	35
1700	927	0.5	3.2	22	2.1*	14*
		1	3.6	25	2.7*	19*
		R	4.6	32	3.2	22
1800	982	0.5	2.1	14	1.2	8.3
		1	2.7	19	1.6	11
		R	3.5	24	2.6	18

* Significant extrapolation
† Values obtained using Larson-Miller interpolation

Creep and Stress Rupture Strengths Continued

Comparative Stress-Rupture Strengths

Test Temperature		10,000 Hour Rupture Strengths (ksi*)							
°F	°C	HR-160®	RA333®	800HT	RA330®	253 MA	RA85H	309	310
1200	649	**15.6**	16.5	17.5	11	14	12	16	9.3
1300	704	**10.8**	12	11	-	8.5	-	-	-
1400	760	**7.4**	9.2	7.3	4.3	5.2	5	5.45	3.9
1500	816	**5.1**	5.7	5.2	-	3.75	-	-	-
1600	871	**3.6**	3.1	3.5	1.7	2.5	2.1	1.86	1.65
1700	927	**2.5**	1.8	1.9	-	1.65	-	-	-
1800	982	**1.8**	1.05	1.2	0.63	1.15	0.9	0.63	0.69

Test Temperature		100,000 Hour Rupture Strengths (ksi*)							
°F	°C	HR-160®**	RA333®	800HT	RA330®	253 MA	RA85H	309	310
1200	649	**11**	11.5	13	7.6	8.7	8	11.6	6.5
1300	704	**7.4**	8.4	8	-	4.6	-	-	-
1400	760	**5**	6.5	5.3	2.7	3.9	3.2	3.8	2.6
1500	816	**3.4**	3.7	3.7	-	2.1	-	-	-
1600	871	**2.4**	1.9	2.5	1	1.45	1.3	1.25	1.06
1700	927	**1.6**	1.05	1.2	-	0.97	-	-	-
1800	982	**1.2**	0.58	0.8	0.33	0.7	0.5	0.41	0.42

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

**Extrapolation.

Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.292 lb/in^3	RT	8.08 g/cm^3
Electrical Resistivity	RT	43.8 µohm.in	RT	111.2 µohm.cm
	200°F	44.3 µohm.in	100°C	112.8 µohm.cm
	400°F	45.2 µohm.in	200°C	114.7 µohm.cm
	600°F	46.1 µohm.in	300°C	116.7 µohm.cm
	800°F	46.9 µohm.in	400°C	118.6 µohm.cm
	1000°F	47.8 µohm.in	500°C	120.6 µohm.cm
	1200°F	48.3 µohm.in	600°C	122.4 µohm.cm
	1400°F	48.6 µohm.in	700°C	123.1 µohm.cm
	1600°F	48.9 µohm.in	800°C	123.8 µohm.cm
	1800°F	49.3 µohm.in	900°C	124.5 µohm.cm
	2000°F	49.6 µohm.in	1000°C	125.2 µohm.cm
	2200°F	49.9 µohm.in	1100°C	125.9 µohm.cm
	-	-	1200°C	126.7 µohm.cm
Thermal Diffusivity	RT	4.6 $10^{-3}in.^2$ sec.	RT	29.4 $10^{-3}cm^2$/sec.
	200°F	4.8 $10^{-3}in.^2$ sec.	100°C	30.8 $10^{-3}cm^2$/sec.
	400°F	5.2 $10^{-3}in.^2$ sec.	200°C	33.6 $10^{-3}cm^2$/sec.
	600°F	5.8 $10^{-3}in.^2$ sec.	300°C	37.0 $10^{-3}cm^2$/sec.
	800°F	6.4 $10^{-3}in.^2$ sec.	400°C	40.6 $10^{-3}cm^2$/sec.
	1000°F	7.0 $10^{-3}in.^2$ sec.	500°C	44.3 $10^{-3}cm^2$/sec.
	1200°F	7.2 $10^{-3}in.^2$ sec.	600°C	45.6 $10^{-3}cm^2$/sec.
	1400°F	7.4 $10^{-3}in.^2$ sec.	700°C	47.2 $10^{-3}cm^2$/sec.
	1600°F	7.5 $10^{-3}in.^2$ sec.	800°C	48.6 $10^{-3}cm^2$/sec.
	1800°F	7.8 $10^{-3}in.^2$ sec.	900°C	48.7 $10^{-3}cm^2$/sec.
	2000°F	8.4 $10^{-3}in.^2$ sec.	1000°C	50.9 $10^{-3}cm^2$/sec.
	2200°F	8.8 $10^{-3}in.^2$ sec.	1100°C	54.1 $10^{-3}cm^2$/sec.
	-	-	1200°C	56.1 $10^{-3}cm^2$/sec.

RT= Room Temperature

Physical Properties Continued

Physical Property	British Units		Metric Units	
Thermal Conductivity	RT	75 Btu.in/h.ft^2.°F	RT	10.9 W/m-°C
	200°F	82 Btu.in/h.ft^2.°F	100°C	12.0 W/m-°C
	400°F	95 Btu.in/h.ft^2.°F	200°C	13.6 W/m-°C
	600°F	108 Btu.in/h.ft^2.°F	300°C	15.4 W/m-°C
	800°F	126 Btu.in/h.ft^2.°F	400°C	17.6 W/m-°C
	1000°F	144 Btu.in/h.ft^2.°F	500°C	19.9 W/m-°C
	1200°F	162 Btu.in/h.ft^2.°F	600°C	21.8 W/m-°C
	1400°F	178 Btu.in/h.ft^2.°F	700°C	24.7 W/m-°C
	1600°F	185 Btu.in/h.ft^2.°F	800°C	26.1 W/m-°C
	1800°F	196 Btu.in/h.ft^2.°F	900°C	26.9 W/m-°C
	2000°F	213 Btu.in/h.ft^2.°F	1000°C	28.7 W/m-°C
	2200°F	228 Btu.in/h.ft^2.°F	1100°C	31.1 W/m-°C
	-	-	1200°C	32.9 W/m-°C
Specific Heat	RT	0.110 Btu/lb.°F	RT	462 J/kg-°C
	200°F	0.116 Btu/lb.°F	100°C	487 J/kg-°C
	400°F	0.121 Btu/lb.°F	200°C	506 J/kg-°C
	600°F	0.125 Btu/lb.°F	300°C	521 J/kg-°C
	800°F	0.131 Btu/lb.°F	400°C	542 J/kg-°C
	1000°F	0.136 Btu/lb.°F	500°C	562 J/kg-°C
	1200°F	0.151 Btu/lb.°F	600°C	597 J/kg-°C
	1400°F	0.159 Btu/lb.°F	700°C	653 J/kg-°C
	1600°F	0.165 Btu/lb.°F	800°C	672 J/kg-°C
	1800°F	0.167 Btu/lb.°F	900°C	689 J/kg-°C
	2000°F	0.171 Btu/lb.°F	1000°C	704 J/kg-°C
	2200°F	0.175 Btu/lb.°F	1100°C	719 J/kg-°C
	-	-	1200°C	732 J/kg-°C
Mean Coefficient of Thermal Expansion	78 - 200°F	7.2 µin./in.-°F	25 - 100°C	13.0 10^{-6} m/m-°C
	78 - 400°F	7.6 µin./in.-°F	25 - 200°C	13.7 10^{-6} m/m-°C
	78 - 600°F	7.9 µin./in.-°F	25 - 300°C	14.0 10^{-6} m/m-°C
	78 - 800°F	8.1 µin./in.-°F	25 - 400°C	14.3 10^{-6} m/m-°C
	78 - 1000°F	8.3 µin./in.-°F	25 - 500°C	14.7 10^{-6} m/m-°C
	78 - 1200°F	8.6 µin./in.-°F	25 - 600°C	15.5 10^{-6} m/m-°C
	78 - 1400°F	8.9 µin./in.-°F	25 - 700°C	15.7 10^{-6} m/m-°C
	78 - 1600°F	9.2 µin./in.-°F	25 - 800°C	16.6 10^{-6} m/m-°C
	78 - 1800°F	9.5 µin./in.-°F	25 - 900°C	17.1 10^{-6} m/m-°C

RT= Room Temperature

Physical Properties Continued

Physical Property	British Units		Metric Units	
Dynamic Modulus of Elasticity	RT	30.6 x 10^6 psi	RT	211 GPa
	100°F	30.5 x 10^6 psi	50°C	210 GPa
	200°F	30.1 x 10^6 psi	100°C	207 GPa
	300°F	29.6 x 10^6 psi	150°C	204 GPa
	400°F	29.1 x 10^6 psi	200°C	201 GPa
	500°F	28.6 x 10^6 psi	250°C	198 GPa
	600°F	27.8 x 10^6 psi	300°C	193 GPa
	700°F	27.1 x 10^6 psi	350°C	189 GPa
	800°F	26.5 x 10^6 psi	400°C	185 GPa
	900°F	26.1 x 10^6 psi	450°C	182 GPa
	1000°F	25.6 x 10^6 psi	500°C	179 GPa
	1100°F	25.1 x 10^6 psi	550°C	176 GPa
	1200°F	24.4 x 10^6 psi	600°C	173 GPa
	1300°F	23.7 x 10^6 psi	650°C	168 GPa
	1400°F	22.9 x 10^6 psi	700°C	163 GPa
	1500°F	22.4 x 10^6 psi	750°C	159 GPa
	1600°F	21.7 x 10^6 psi	800°C	155 GPa
	1700°F	21.1 x 10^6 psi	850°C	151 GPa
	1800°F	19.8 x 10^6 psi	900°C	147 GPa
	-	-	950°C	266 GPa

RT= Room Temperature

Physical Metallurgy

-	Typical Grain Size	Average Hardness
Plate	3 - 4½	89
Bar	2 - 3	85
Sheet	3½ - 4½	88

Annealed Microstructure

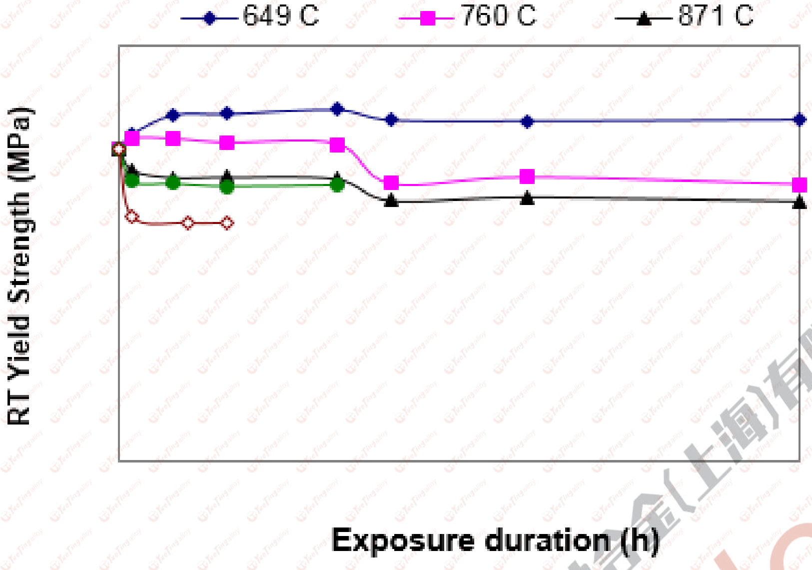
The alloy has a stable austenitic structure and exhibits no sigma or mu phases after long-term aging. Aging at 1200, 1400 and 1600°F (649, 760 and 871°C) for 4000 hours, for example, resulted in the precipitation of $Cr_{23}C_6$ and G phase ($Ni_{16}Ti_6Si_7$). The morphology of G phase is quite similar to that of $Cr_{23}C_6$. Thus, G phase is not considered to be more detrimental than carbides in causing the ductility to drop upon long-term aging. The alloy is non-magnetic in annealed and coldworked conditions.

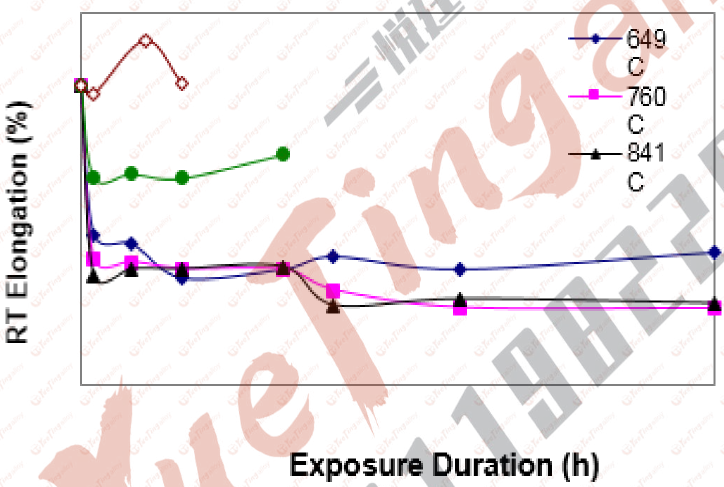
Thermal Stability

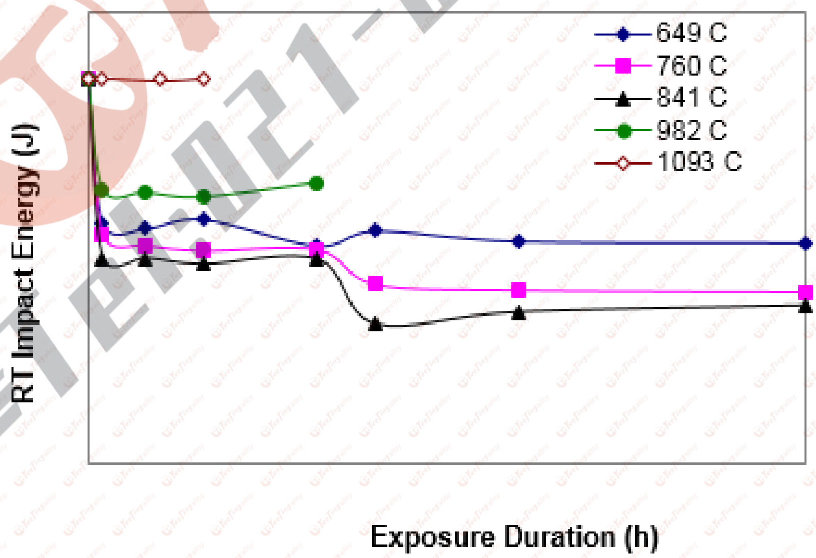
Exposure Temperature		Exposure Duration	0.2% Yield strength		Ultimate Tensile Strength		4D Elongation	AGL* Elongation	RA	Impact energy	
°F	°C	h	ksi	MPa	ksi	MPa	%	%	%	ft-lb	J
-	-	0	49	338	119.7	825	64.1	59.6	70.6	263	357
1200	649	1000	51.5	355	123.6	852	32.2	32.8	28.8	29	39
1200	649	4000	54.5	376	131.4	906	30.2	30	26.4	27	36
1200	649	8000	54.7	377	130.4	899	23.1	22.8	20	23	31
1200	649	16000	55.3	381	135.8	936	24.7	23.4	20.8	21	28
1200	649	20000	53.7	370	129.1	890	27.4	27.1	24.6	26	35
1200	649	30000	53.5	369	131.3	905	24.7	24.2	23.7	22	30
1200	649	50000	53.8	371	134.5	927	28.3	26.4	22.1	21	29
1400	760	1000	50.8	350	131.1	904	26.8	26.9	22.2	24	33
1400	760	4000	50.6	349	131.1	904	26.3	26.1	26	21	28
1400	760	8000	50	345	130.1	897	24.8	25.1	22.5	19	26
1400	760	16000	49.9	344	130.7	901	24.6	25	21.2	19	26
1400	760	20000	43.7	301	107.9	744	20.2	19.3	14	12	16
1400	760	30000	44.7	308	102.4	706	-	16.4	11.3	10	14
1400	760	50000	43.5	300	102.3	705	-	16.2	12.4	10	13
1600	871	1000	45.7	315	114.6	790	23.2	23.8	20.8	17	23
1600	871	4000	44.5	307	114	786	24.8	25.1	20.5	17	23
1600	871	8000	44.7	308	114.9	792	24.8	25.3	22.6	15	21
1600	871	16000	44.4	306	115	793	25.2	25.9	22.2	16	22
1600	871	20000	41	283	88.6	611	17	17.2	15.1	6	8
1600	871	30000	41.6	287	89.9	620	18.3	18.1	15.3	7	10
1600	871	50000	40.9	282	86.2	594	17.4	17.6	14.5	8	11
1800	982	1000	43.9	303	119.1	821	44.6	44.9	39	49	66
1800	982	4000	43.7	301	117.5	810	45.3	44.5	39.2	46	63
1800	982	8000	43.2	298	115.3	795	44.4	43.6	38	44	59
1800	982	16000	43.4	299	114.3	788	49.4	48.5	42	54	73
2000	1093	1000	38.4	265	104.4	720	62.3	64.3	62.8	264	358
2000	1093	5065	37.6	259	99.5	686	74	72.1	65.4	263	357
2000	1093	8000	37.6	259	100.2	691	64.6	67.1	60.1	264	358

*AGL is adjusted gauge length and AGL % elongation is useful when tensile fracture
RA= Reduction of Area

Thermal Stability Continued







Aqueous Corrosion Resistance

Stress Corrosion Cracking

Alloy	Time to Failure, h.	
HR-160®	**1000h**	**No Cracking**
C-22®	1000h	No Cracking
825	150h	Cracked
316LSS	24h	Cracked

Uniform Corrosion

	Average Corrosion Rate Per Year, mils*		
-	**HR-160®**	**625**	**316L**
3% HCl + 59% HNO_3, 80°C	**2**	20	-
1% HF + 20% HNO_3, 80°C	**35**	123	>400
50% H_2SO_4 + 10% HNO_3, Boiling	**20**	-	-
60% H_2SO_4 + 5% HNO_3, Boiling	**50**	105	-
65% HNO_3, Boiling	**9**	20	12
50% H_2SO_4 + 42 g/l $Fe_2(SO_4)_3$ G-28A, Boiling	**9**	24	38
25% H_2SO_4 + 5% HNO_3 + 4% NaCl, Boiling	**3**	713	-
1% HCl, Boiling	**469**	0.9	524
1% HCl + 1% H_2SO_4 + 1% HF, 79°C	**107**	120	245

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

Welding

HAYNES® HR-160® alloy is readily weldable by Gas Tungsten Arc (TIG) and Gas Metal Arc (MIG) welding processes. Many of the alloy's welding characteristics are similar to those for the HASTELLOY® alloys and the same precautions apply. Submerged arc welding is not recommended as this process is characterized by high heat input which could result in distortion and hot cracking. HR-160® filler metal is prone to start/stop cracking. The filler metal may be prone to hot cracking when welding heavy plate (e.g. greater than 1/2 inch thick) under highly restrained conditions. Any localized cracking should be removed by grinding prior to further welding. Do not attempt to remelt or "wash-out" welding cracks.

Base Metal Preperation

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. It is preferable, but not mandatory, that the alloy be in the solutionannealed condition when welded.

Filler Metal Selection

Matching composition filler metal is recommended for joining HR-160® alloy. When dissimilar base metals are to be jointed, such as HR-160® alloy to a stainless steel, HAYNES® 556® filler metal is recommended.

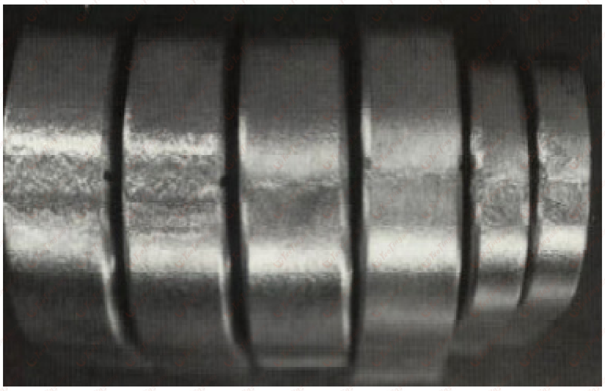
Preheating, Interpass Temperatures and Post Weld Heat Treatment

Preheat should not be used so long as the base metal to be welded is above 32°F (0°C). Interpass temperatures should be less than 200°F (93°C). Auxiliary cooling methods may be used between weld passes, as needed, providing that such methods do not introduce contaminants. Post-weld heat treatment is not normally required for HR-160® alloy.

Nominal Welding Parameters

Nominal welding parameters are provided as a guide for performing typical operations. These are based on welding conditions used in our laboratory and should be considered only as a guideline. For further information, please consult our “Welding and Fabrication” brochure.

Large Welded retort fabricated from 0.375 inch (9.5 mm) HR-160® plate.



Typical face, root and side bends for HR-160® alloy. The plate thickness was 0.5 inch (12.7 mm) and the bend radius 1.0 inch (25 mm) (2T radius).

Welding Continued

AWM Tensile

Type	Test Temperature		Ultimate Tensile Strength		0.2% Yield Strength		Elongation
	°F	°C	ksi	MPa	ksi	MPa	%
GMAW	RT	RT	94.1	649	58.0	400	26.4
	500	260	81.9	565	45.8	316	25.2
	1000	538	71.3	492	42.8	295	32.4
	1400	760	43.2	298	33.7	232	29.6
	1600	871	22.7	157	17.6	121	33.3
GTAW	RT	RT	101.3	698	68.5	472	26.4
	500	260	81.7	563	47.2	325	32.1
	1000	538	70.4	485	42.8	295	43.7
	1400	760	46.3	319	34.4	237	30.0
	1600	871	22.6	156	18.1	125	72.2

All-Weld Metal samples
RT= Room Temperature

Welded Transverse Tensile

Condition	Test Temperature		Ultimate Tensile Strength		0.2% Yield Strength		Elongation
	°F	°C	ksi	MPa	ksi	MPa	%
As-Welded	RT	RT	102.3	705	60.1	414	30.6
	500	260	82.9	572	49.5	341	32.0
	1000	538	75.3	519	47.1	325	39.5
	1400	760	45.4	313	31.3	216	26.3
	1600	871	23.6	163	18.6	128	33.9
Aged*	RT	RT	98.7	680	52.8	364	18.1

GTAW welded transverse tensile samples
*Samples aged at 1600°F (871°C) for 1000 hours
RT= Room Temperature

Welded Creep Rupture

Test Temperature		Stress		1% Creep Life	5% Creep Life	Rupture Life	Elongation
°F	°C	ksi	MPa	h	h	h	%
1200	649	30.0	207	12.9	67.0	110.7	13.7
1400	760	18.0	124	5.0	13.1	29.2	22.0
1600	871	11.5	79	49.0	67.5	114.6	26.9
1700	927	6.0	41	61.0	94.0	152.4	33.9

Specifications and Codes

Specifications

<table>
<tr><th colspan="2">HAYNES® HR-160® alloy
(N12160)</th></tr>
<tr><td>Sheet, Plate & Strip</td><td>SB 435/B 435
P= 46</td></tr>
<tr><td>Billet, Rod & Bar</td><td>SB 572/B 572
B 472
P= 46</td></tr>
<tr><td>Coated Electrodes</td><td>-</td></tr>
<tr><td>Bare Welding Rods & Wire</td><td>SFA 5.14/ A 5.14 (ERNiCoCrSi-1)
F= 46</td></tr>
<tr><td>Seamless Pipe & Tube</td><td>SB 622/B 622
P= 46</td></tr>
<tr><td>Welded Pipe & Tube</td><td>SB 619/B 619
SB 626/B 626
P= 46</td></tr>
<tr><td>Fittings</td><td>SB 366/B 366
P= 46</td></tr>
<tr><td>Forgings</td><td>SB 564/B 564
P= 46</td></tr>
<tr><td>DIN</td><td>No. 2.4880
NiCo29Cr28Si</td></tr>
<tr><td>Others</td><td>ASME Code Case
No. 2385</td></tr>
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Codes

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(N12160)</th></tr>
<tr><td rowspan="12">ASME</td><td>Section I</td><td colspan="2">-</td></tr>
<tr><td rowspan="3">Section III</td><td>Class 1</td><td>-</td></tr>
<tr><td>Class 2</td><td>-</td></tr>
<tr><td>Class 3</td><td>-</td></tr>
<tr><td>Section IV</td><td>HF-300.2</td><td>-</td></tr>
<tr><td rowspan="2">Section VIII</td><td>Div. 1</td><td>1800°F (982°C)[1,2]</td></tr>
<tr><td>Div. 2</td><td>-</td></tr>
<tr><td>Section XII</td><td colspan="2">-</td></tr>
<tr><td>B16.5</td><td colspan="2">-</td></tr>
<tr><td>B16.34</td><td colspan="2">-</td></tr>
<tr><td>B31.1</td><td colspan="2">-</td></tr>
<tr><td>B31.3</td><td colspan="2">-</td></tr>
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[1]Approved material forms: Plate, Sheet, Bar, Forgings, fittings, welded pipe/tube, seamless pipe/tube
[2]ASME Code Case No. 2385

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