HASTELLOY® S alloy

Principal Features

HASTELLOY® S (UNS N06635) is a nickel-base, high-temperature alloy with a unique combination of properties. It has excellent thermal stability, low thermal expansion and excellent oxidation resistance to 2000 °F (1093 °C). In addition, the alloy has good high-temperature and thermal fatigue strength. S alloy retains its strength and ductility after aging at temperatures of 800 to 1600 °F (427 to 871 °C).

S alloy was developed for applications involving severely cyclical heating conditions where components must be capable of retaining their strength, ductility, and metallurgical integrity after long-time exposure. It is used extensively as seal rings in gas turbine engines where its low thermal expansion coefficients is also important.

HATELLOY® S alloy is available in the form of plate, sheet, strip, billet, bar, wire, pipe, and tubing.

All wrought forms of S alloy are supplied in the solution heat-treated condition unless otherwise specified. The standard heat-treatment is 1950 °F (1066 °C) followed by cooling in air or hydrogen. Since the alloy is very stable, cooling rates from slow-furnace cooling to rapid ice-brine quenching have virtually no effect on the mechanical properties.

HASTELLOY® S alloy can be readily forged and, because of its excellent ductility, can be cold worked. It can be welded by both manual and automatic welding methods including gas tungsten arc (GTAW), and gas metal arc (GMAW). Forging should be performed from 2100 °F (1145 °C) to 1600 °F (871 °C) up to the final 20 percent cross-section reduction. The final 20 percent reduction should be done from about 1900 °F (1038 °C) to 1500 °F (816 °C).

Nominal Composition

Weight %

Nickel:	67 Balance
Cobalt:	2 max.
Chromium:	16
Molybdenum:	15
Iron:	3 max.
Silicon:	0.4
Manganese:	0.5
Carbon:	0.02 max.
Aluminum:	0.25
Boron:	0.015 max.
Lanthanum:	0.02
Tungsten:	1 max.

Physical Properties

Physical Property	British Units		Metric Units	
Density	72°F	0.316 lb/in³	22°C	8.75 g/cm³
Melting Temperature	2435-2516°F	-	1335-1380°C	-
Electrical Resistivity	77°F	50.4a µohm-in	25°C	1.28a µohm-m
Thermal Conductivity	392°F	97 Btu-in/ft²-hr-°F	200°C	14.0 W/m-°C
	572°F	112 Btu-in/ft²-hr-°F	300°C	16.1 W/m-°C
	752°F	124 Btu-in/ft²-hr-°F	400°C	17.9 W/m-°C
	932°F	135 Btu-in/ft²-hr-°F	500°C	19.5 W/m-°C
	1112°F	146 Btu-in/ft²-hr-°F	600°C	21.0 W/m-°C
	1292°F	181 Btu-in/ft²-hr-°F	700°C	26.1 W/m-°C
	1472°F	181 Btu-in/ft²-hr-°F	800°C	26.1 W/m-°C
	1652°F	181 Btu-in/ft²-hr-°F	900°C	26.1 W/m-°C
	1742°F	188 Btu-in/ft²-hr-°F	950°C	27.1 W/m-°C
	1832°F	194 Btu-in/ft²-hr-°F	1000°C	28.0 W/m-°C
Thermal Diffusivity	212°F	0.006 in²/s	100°C	$3.9 \times 10^{-6} m^2/s$
	392°F	0.006 in²/s	200°C	$3.9 \times 10^{-6} m^2/s$
	572°F	0.006 in²/s	300°C	$3.9 \times 10^{-6} m^2/s$
	752°F	0.007 in²/s	400°C	$4.5 \times 10^{-6} m^2/s$
	932°F	0.007 in²/s	500°C	$4.5 \times 10^{-6} m^2/s$
	1112°F	0.008 in²/s	600°C	$5.2 \times 10^{-6} m^2/s$
	1292°F	0.008 in²/s	700°C	$5.2 \times 10^{-6} m^2/s$
	1472°F	0.008 in²/s	800°C	$5.2 \times 10^{-6} m^2/s$
	1652°F	0.008 in²/s	900°C	$5.2 \times 10^{-6} m^2/s$
	1742°F	0.008 in²/s	950°C	$5.2 \times 10^{-6} m^2/s$
	1832°F	0.009 in²/s	1000°C	$5.8 \times 10^{-6} m^2/s$

Physical Properties Continued

Physical Property	British Units		Metric Units	
Specific Heat	32°F	0.095 Btu/lb-°F	0°C	398 J/kg-°C
	122°F	0.099 Btu/lb-°F	50°C	414 J/kg-°C
	212°F	0.102 Btu/lb-°F	100°C	427 J/kg-°C
	302°F	0.105 Btu/lb-°F	150°C	440 J/kg-°C
	392°F	0.107 Btu/lb-°F	200°C	448 J/kg-°C
	482°F	0.109 Btu/lb-°F	250°C	456 J/kg-°C
	572°F	0.111 Btu/lb-°F	300°C	465 J/kg-°C
	662°F	0.113 Btu/lb-°F	350°C	473 J/kg-°C
	752°F	0.114 Btu/lb-°F	400°C	477 J/kg-°C
	842°F	0.115 Btu/lb-°F	450°C	481 J/kg-°C
	932°F	0.117 Btu/lb-°F	500°C	490 J/kg-°C
	1022°F	0.118 Btu/lb-°F	550°C	494 J/kg-°C
	1112°F	0.119 Btu/lb-°F	600°C	498 J/kg-°C
	1202°F	0.120 Btu/lb-°F	650°C	502 J/kg-°C
	1292°F	0.142 Btu/lb-°F	700°C	594 J/kg-°C
	1382°F	0.142 Btu/lb-°F	750°C	594 J/kg-°C
	1472°F	0.141 Btu/lb-°F	800°C	590 J/kg-°C
	1562°F	0.142 Btu/lb-°F	850°C	594 J/kg-°C
	1652°F	0.142 Btu/lb-°F	900°C	594 J/kg-°C
	1742°F	0.143 Btu/lb-°F	950°C	598 J/kg-°C
	1832°F	0.143 Btu/lb-°F	1000°C	598 J/kg-°C
	1922°F	0.143 Btu/lb-°F	1050°C	598 J/kg-°C
	2012°F	0.144 Btu/lb-°F	1100°C	603 J/kg-°C
Mean Coefficient of Thermal Expansion	68-200°F	6.4 µin/in-°F	20-93°C	11.5 x 10^{-6}m/m-°C
	68-400°F	6.8 µin/in-°F	20-204°C	12.2 x 10^{-6}m/m-°C
	68-600°F	7.1 µin/in-°F	20-316°C	12.8 x 10^{-6}m/m-°C
	68-800°F	7.3 µin/in-°F	20-427°C	13.1 x 10^{-6}m/m-°C
	68-1000°F	7.4 µin/in-°F	20-538°C	13.3 x 10^{-6}m/m-°C
	68-1200°F	7.6 µin/in-°F	20-649°C	13.7 x 10^{-6}m/m-°C
	68-1400°F	8.0 µin/in-°F	20-760°C	14.4 x 10^{-6}m/m-°C
	68-1600°F	8.3 µin/in-°F	20-871°C	14.9 x 10^{-6}m/m-°C
	68-1800°F	8.6 µin/in-°F	20-982°C	15.5 x 10^{-6}m/m-°C
	68-2000°F	8.9 µin/in-°F	20-1093°C	16.0 x 10^{-6}m/m-°C
Dynamic Modulus of Elasticity	75°F	30.8 x 10^{6} psi	24°C	212 GPa
	675°F	28.2 x 10^{6} psi	357°C	194 GPa
	1000°F	26.4 x 10^{6} psi	538°C	182 GPa
	1200°F	25.2 x 10^{6} psi	649°C	174 GPa
	1400°F	24.1 x 10^{6} psi	760°C	166 GPa
	1495°F	23.3 x 10^{6} psi	813°C	161 GPa
	1700°F	21.9 x 10^{6} psi	927°C	151 GPa
	2000°F	19.2 x 10^{6} psi	1093°C	132 GPa

Oxidation Resistance

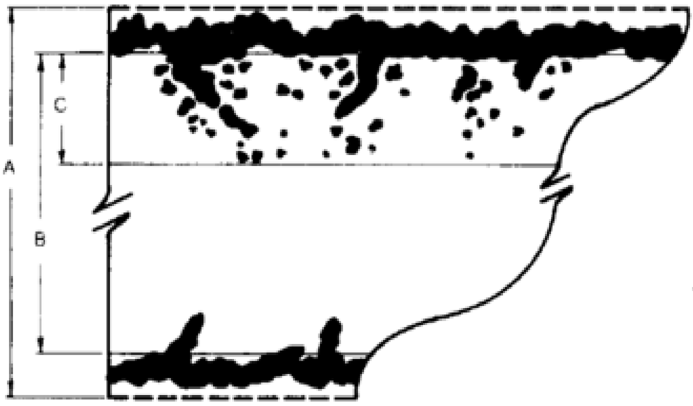
Comparative Static Oxidation Resistance 1008 Hour Static Oxidization in Flowing Air*

Test Temperature		Alloy	Metal Loss		Metal Loss and Internal Penetration		Linearly Extrapolated Rate of Attack	
°F	°C	-	mils	mm	mils	mm	mils/y	mm/y
1800	982	214®	0.07	0.002	0.2	0.005	1.7	0.043
		S	**0.18**	**0.005**	**0.49**	**0.012**	**4.3**	**0.109**
		188	0.18	0.005	0.58	0.015	5	0.127
		230®	0.25	0.006	0.71	0.018	6.2	0.158
		625	0.32	0.008	0.72	0.018	6.3	0.16
		600	0.32	0.008	0.9	0.023	7.8	0.198
		X	0.34	0.009	0.94	0.024	8.2	0.208
		556®	0.39	0.01	1.05	0.027	9.1	0.218
		310 SS	0.35	0.009	1.13	0.029	9.8	0.249
		800H	0.94	0.024	1.79	0.045	15.6	0.396
2000	1093	214®	0.08	0.002	0.08	0.002	0.7	0.018
		230®	0.45	0.011	1.27	0.032	11	0.279
		S	**0.44**	**0.011**	**1.29**	**0.033**	**11.2**	**0.285**
		310 SS	0.97	0.023	1.3	0.033	11.3	0.287
		188	0.43	0.01	1.33	0.033	11.6	0.29
		600	1.1	0.027	1.63	0.041	14.1	0.358
		556®	0.97	0.027	2.57	0.065	22.3	0.566
		X	1.49	0.038	2.72	0.069	23.6	0.599
		625	3.27	0.083	4.8	0.122	41.7	1.059
		800H	5.39	0.137	7.39	0.188	64.2	1.631
2100	1149	214®	0.15	0.004	0.31	0.008	2.7	0.069
		S	**1.01**	**0.026**	**1.66**	**0.042**	**14.4**	**0.366**
		600	1.73	0.044	2.86	0.073	24.9	0.633
		230®	2.29	0.058	3.44	0.087	29.9	0.76
		310 SS	2.97	0.075	4.44	0.113	38.6	0.98
		X	4.5	0.114	5.83	0.148	50.6	1.285
		188	7.23	0.184	8.03	0.204	69.8	1.773
		800H	7.52	0.191	8.86	0.225	77	1.956
		556®	9.31	0.237	11.64	0.296	101.2	2.571
		625	15.96	0.405	18.2	0.462	158.2	4.018

*Cycled to room temperature once a week

Oxidation Resistance Continued

Schematic of Metallographic Technique Used for Dynamic Oxidation and Hot Corrosion Evaluations



Metal Loss (mils/side) $\left[\left(\frac{A-B}{2}\right)\right]$

Maximum Penetration (mils/side) [C]

Total Metal Affected (mils/side) $\left[\left(\frac{A-B}{2} + C\right)\right]$

Average Dynamic Oxidation Resistance*

Test Temperature		Test Period	Metal Loss/Side		Maximum Penetration Side		Total Metal Affected/Side	
°F	°C	h	mils	mm	mils	mm	mils	mm
1600	871	100	1	0.03	0.3	0.01	1.3	0.03
1800	982	100	1.4	0.04	0.7	0.02	2.2	0.06
2000	1093	100	1.6	0.04	2.2	0.06	3.8	0.1

*Samples exposed to the combustion products of No. 2 fuel oil (0.4 percent sulfur). Hot gas velocity was 280ft./sec. (85mm/sec). Thermal shock frequency was 2 cycles per hour, consisting of cooling from test temperature to <500°F (<260°C) and back to test temperature in two minutes.

Comparative Average Dynamic Oxidation Resistance

Test Temperature		Test Period	Maximum Metal Affected/Side**							
			S		230®		X		25	
°F	°C	h	mils	mm	mils	mm	mils	mm	mils	mm
1800	982	1000	**6.6**	**0.17**	3.5	0.09	6.4	0.16	7.6	0.19
2000	1093	500	**15.2**	**0.39**	5.7	0.14	13.5	0.34	<31.0***	0.79***

*Samples exposed to the combustion products of No. 2 fuel oil (0.4 percent sulfur). Hot gas velocity was 280ft./sec. (85mm/sec). Thermal shock frequency was 2 cycles per hour, consisting of cooling from test temperature to <500°F (<260°C) and back to test temperature in two minutes.

**Metal loss plus maximum internal penetration

***Sample was consumed

Corrosion Resistance

Average Hot Corrosion Resistance

Test Temperature		Test Period	Metal Loss/Side		Maximum Penetration/Side		Total Metal Affected/Side	
°F	°C	h	mils	mm	Mils	mm	Mils	mm
1650	899	200	1.2	0.03	1.5	0.04	2.7	0.07
1650	899	1000	4	0.1	3.5	0.09	7.5	0.19

Comparative Average Hot Corrosion Resistance

Test Temperature		Test Period	Total Metal Affected/Side					
			S		188		X	
°F	°C	h	mils	mm	mils	mm	mils	mm
1650	899	200	**2.7**	**0.07**	1.5	0.04	2.7	0.07
1650	899	1000	**7.5**	**0.19**	3.5	0.09	7.5	0.19

* All tests performed by exposure to the combustion products of No. 2 fuel oil (0.4 percent sulfur) and 5 ppm of sea salt. Gas velocity over samples was 13 ft/sec (4 m/s). Thermal stock frequency was one hour.

Comparative Nitriding Resistance

1200°F for 168 Hours in NH_3

Alloy	Depth of Nitrided Layer		Nitrogen Absorption
-	mils	mm	(mg/cm^2)
230®	1.2	0.03	0.7
600	1.3	0.03	0.8
S	**1.1**	**0.03**	**1.3**
214®	1.5	0.04	1.5
800H	4.1	0.1	4.3
304 SS	8.4	0.21	9.8

Comparative Carburization Resistance

1800°F for 55 Hours in 5%CO-5%CH4-5%H2-Ar

Alloy	Carbon Absorption (mg/cm2)
214®	0.6
S	**2.1**
230®	2.5
X	2.5
310 SS	3.3
601	4.8

Comparative Molten Chloride Salt Resistance

1550 °F for 1 Month in $BaCl_2$-KCl-NaCl Mixed Salts

Alloy	Metal Loss Plus Internal Penetration	
-	Mils	mm
188	27	0.69
S	**40**	**1.02**
304 SS	75	1.91
600	96	2.44
601 alloy	115	2.92

Hardness

Room Temperature*

Form	Aging Temperature		Aging Time	Hardness
	°F	°C	h	HRA
Plate	Solution Heat-treated		-	57
	800	427	1000	57
			4000	52
			8000	52
			16000	56
	1000	538	1000	64
			4000	63
			8000	65
			16000	67
	1200	649	1000	57
			4000	55
			8000	56
			16000	57
	1400	760	1000	57
			4000	57
			8000	56
			16000	57
	1600	871	1000	56
			4000	56
			8000	54
			16000	54
All Weld Metal**	As-Welded		-	56
	1000	538	1300	64
			4000	66
	1200	649	1000	55
			4000	59
			8000	57
			16000	58

*Single tests from a single hear for each form

**Gas tungsten arc welded

HRA = Hardness Rockwell “A”.

Impact Strength

Aged Plate*

Aging Temperature		Aging Time	Average Charpy V-Notch Impact Strength	
°F	°C	h	ft. lbs.	J
Solution Heat-Treated		-	140	190
800	427	1000	147**	199**
		4000	147**	199**
		8000	147**	199**
		16000	130	176
1000	538	1000	114	155
		4000	76	104
		8000	67	90
		16000	47	64
1200	649	1000	85	115
		4000	67	91
		8000	54	73
		16000	49	66
1400	760	1000	79	107
		4000	52	71
		8000	48	65
		16000	39	53
1600	871	1000	107	145
		4000	109	148
		8000	105	142
		16000	109	148

*Average of four tests of 1/2in (12.7m) plate from a single heat
**Specimen did not fracture into two pieces

Tensile Data

Form	Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
Sheet	°F	°C	ksi	MPa	ksi	MPa	%
0.045 to 0.063 in (1.1 to 1.6 mm) thick	RT	RT	64.5	444	129.8	844	49
	1000	538	49.1	338	112.3	773	50
	1200	649	46.7	322	104.5	720	56
	1400	760	45.1	311	84.1	574	70
	1600	871	31.6	218	48.6	341	47
	1800	982	16	110	28	193	46
	2000	1093	7.6	52	15.9	110	75
Plate 3/8 to 1-in (9.5 to 25.4 mm) thick	RT[a]	RT[a]	55.6	383	123.1	849	55
	200	93	52.9	365	118	814	60
	400	204	48	331	114.4	789	59
	600	316	42.2	291	109.7	756	63
	800	427	43.1	297	108.9	751	62
	1000	538	41	283	105.9	727	61
	1200	649	39.8	274	99.1	683	59
	1400	760	39.3	271	79.3	547	69
	1600	871	33.8	233	52.7	363	57
	1800	982	19.6	135	33	228	62
	2000	1093	8.8	61	17	117	69

a-Based pm 34 tests. At other temperatures, the number of tests varied from 7-23.
RT=Room Temperature

Tensile Data Continued

Average Aged Tensile Data, Room Temperature*

Form	Aging Temperature		Aging Time	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
	°F	°C	h	MPa	ksi	ksi	MPa	%
Sheet 0.057 in (1.45 mm) thick	Solution Heat-treated		-	128.6	887	63	434	58
	1000	538	1000	1231	178.6	109.2	753	45
			4000	1253	181.7	107.5	741	41
			8000	1276	185.1	119.1	821	41
			16000	1288	186.8	120.5	831	38
	1200	649	1000	920	133.4	69.3	478	56
			4000	898	130.3	66.3	457	52
			8000	914	132.5	65.9	454	54
			16000	918	133.1	68.4	472	50
	1400	760	1000	919	133.3	66.6	459	54
			4000	910	132.2	64.9	447	51
			8000	904	131.1	65.3	450	54
			16000	885	128.3	62.6	432	52
Plate ½ in (12.7 mm) thick	Solution Heat-treated		-	125.3	864	52.9	365	54
	800	427	1000	867	125.7	55.9	385	60
			4000	875	126.9	55.5	383	60
			8000	874	126.7	56.6	390	55
			16000	883	128	57.9	399	56
	1000	538	1000	996	144.4	71.5	493	46
			4000	1207	175	102.5	707	44
			8000	1247	180.8	108.2	746	38
			16000	1258	182.5	108.9	751	39
	1200	649	1000	863	125.1	56.6	390	57
			4000	867	125.8	56.4	389	54
			8000	877	127.2	57	393	50
			16000	882	127.9	59.3	409	49
	1400	760	1000	869	126	53.7	370	55
			4000	878	127.5	54.1	373	52
			8000	879	127.5	53.5	369	46
			16000	879	127.5	53.9	372	47
	1600	871	1000	867	125.8	50.8	350	58
			4000	863	125.2	50.7	350	56
			8000	852	123.5	51.3	354	53
			16000	850	123.3	50.5	348	56

*Test Data for each form are from a single heat.

Tensile Data Continued

Average Welded and Aged Tensile Data, Room Temperature*

Form	Aging Temperature		Aging Time	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
	°F	°C	h	ksi	Mpa	ksi	MPa	%
Gas Tungsten arc Welded Plate ½ in (12.7mm) Thick	Solution Heat-treated		-	59.8	412	112.4	775	62
			1000	63.3	436	121.7	839	33
			4000	60.4	416	122.8	847	32
	1200	649	8000	62.2	429	119.1	821	26
			16000	63.6	439	155.6	1073	25
All Weld Metal**	Solution Heat-treated		-	66.6	459	105.1	725	55
			1300**	98.4	678	139.8	964	24
	1000	538	4000**	107.6	742	145.6	1004	26
			1000	60.7	419	102.5	707	24
			4000	52.9	365	110.3	760	25
	1200	649	8000	61.7	425	102.3	705	20
			16000	66.4	458	110.3	760	21

*Test data for each form are form a single heat

**Gas tungsten arc welded

Creep and Stress-Rupture Strengths

Rupture Data

Sheet*

Test Temperature		Average Rupture Life Strength for Time Indicated					
		10 h		100 h		1000 h	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	62.5	431	50	345	38	262
1350	732	39	269	28.2	194	20.2	139
1500	816	23.5	162	15	103	9.9	68
1700	927	9.6	66	5.8	40	-	-

*0.045 in (1.1 mm) to 0.063 in (1.6 mm) thick

Plate*

Test Temperature		Average Rupture Life Strength for Time Indicated					
		10 h		100 h		1000 h	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	80	552	58	400	27	186
1300	704	56	386	38	262	16	110
1400	760	38	262	24.5	169	9.8	68
1500	816	25	172	16	110	5.8	40
1600	871	16.5	114	9.8	68	3	21

*1-in. (25.4mm) thick plate

Creep and Stress-Rupture Strengths Continued

Creep Data

Sheet*

Test Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in:					
			10 h		100 h		1,000 h	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	0.2	45	310	31.5	217	21	145
		0.5	50	345	35.5	245	24	165
		1	56.5	390	40	276	27	186
1350	732	0.2	22	152	14.1	97	9	62
		0.5	25	172	16.2	112	10.4	72
		1	29	200	19	131	12.2	84
1500	816	0.2	10.2	70	5.9	41	-	-
		0.5	11.8	81	7	48	-	-
		1	13.8	95	8.4	58	-	-

*0.045 in (1.1 mm) to 0.063 (1.6 mm) thick

Plate*

Test Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in:							
			10 h		100 h		1,000 h		10,000 h	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	0.2	45	310	27	186	17.0**	117**	-	-
		0.5	54	372	32.6	255	19	131	-	-
		1	56	386	34	234	20.8	143	13.5	93
1300	704	0.2	24	165	12.5	86	6.7**	46**	-	-
		0.5	29	200	16.5	114	9	62	-	-
		1	34	234	20	138	12	83	7.2	50
1400	760	0.2	13	90	6.5	45	3.3**	23**	-	-
		0.5	16.9	117	9.2	63	4.8	33	-	-
		1	20.7	143	11.8	81	6.7	46	3.7	26
1500	816	0.2	7.8	54	3.8	26	1.9**	13**	-	-
		0.5	10	69	5.7	39	3	21	-	-
		1	12.5	86	6.9	48	3.8	26	2.2	15
1600	871	0.2	4.7	32	2.2	15	1.1**	7.6**	-	-
		0.5	6.3	43	3.5	24	1.9	13	-	-
		1	7.6	52	4.1	28	2.2	15	1.1	8

*1 in (25.4 mm) thick plate
**Extrapolated

Disclaimer:
Haynes International makes all reasonable efforts to ensure the accuracy and correctness of the data in this document but makes no representations or warranties as to the data's accuracy, correctness or reliability. All data are for general information only and not for providing design advice. Alloy properties disclosed here are based on work conducted principally by Haynes International, Inc. and occasionally supplemented by information from the open literature and, as such, are indicative only of the results of such tests and should not be considered guaranteed maximums or minimums. It is the responsibility of the user to test specific alloys under actual service conditions to determine their suitability for a particular purpose.

For specific concentrations of elements present in a particular product and a discussion of the potential health affects thereof, refer to the Safety Data Sheets supplied by Haynes International, Inc. All trademarks are owned by Haynes International, Inc., unless otherwise indicated.