HASTELLOY® S alloy

HASTELLOY® S alloy (UNS N06635) offers excellent thermal stability, good thermal fatigue resistance, good oxidation-resistance and relatively low expansion characteristics. Used in low-stress gas turbine parts.

Principal Features

HASTELLOY® S alloy (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.

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-fumace 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

Average Physical Properties

Physical Property	Britsih Units		Metric Units	
Density	72°F	0.316 lb/in^3	22°C	8.75 g/cm^3
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/ft^2-hr-°F	200°C	14.0 W/m-°C
	572°F	112 Btu-in/ft^2-hr-°F	300°C	16.1 W/m-°C
	752°F	124 Btu-in/ft^2-hr-°F	400°C	17.9 W/m-°C
	932°F	135 Btu-in/ft^2-hr-°F	500°C	19.5 W/m-°C
	1112°F	146 Btu-in/ft^2-hr-°F	600°C	21.0 W/m-°C
	1292°F	181 Btu-in/ft^2-hr-°F	700°C	26.1 W/m-°C
	1472°F	181 Btu-in/ft^2-hr-°F	800°C	26.1 W/m-°C
	1652°F	181 Btu-in/ft^2-hr-°F	900°C	26.1 W/m-°C
	1742°F	188 Btu-in/ft^2-hr-°F	950°C	27.1 W/m-°C
	1832°F	194 Btu-in/ft^2-hr-°F	1000°C	28.0 W/m-°C
Thermal Diffusivity	212°F	0.006 in^2/s	100°C	3.9 x 10^{-6}m^2/s
	392°F	0.006 in2/s	200°C	3.9 x 10^{-6}m^2/s
	572°F	0.006 in^2/s	300°C	3.9 x 10^{-6}m^2/s
	752°F	0.007 in^2/s	400°C	4.5 x 10^{-6}m^2/s
	932°F	0.007 in^2/s	500°C	4.5 x 10^{-6}m^2/s
	1112°F	0.008 in^2/s	600°C	5.2 x 10^{-6}m^2/s
	1292°F	0.008 in^2/s	700°C	5.2 x 10^{-6}m^2/s
	1472°F	0.008 in^2/s	800°C	5.2 x 10^{-6}m^2/s
	1652°F	0.008 in^2/s	900°C	5.2 x 10^{-6}m^2/s
	1742°F	0.008 in^2/s	950°C	5.2 x 10^{-6}m^2/s
	1832°F	0.009 in^2/s	1000°C	5.8 x 10^{-6}m^2/s

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 10-6m/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 10^6psi	24°C	212 GPa
	675°F	28.2 x 10^6psi	357°C	194 GPa
	1000°F	26.4 x 10^6psi	538°C	182 GPa
	1200°F	25.2 x 10^6psi	649°C	174 GPa
	1400°F	24.1 x 10^6psi	760°C	166 GPa
	1495°F	23.3 x 10^6psi	813°C	161 GPa
	1700°F	21.9 x 10^6psi	927°C	151 GPa
	2000°F	19.2 x 10^6psi	1093°C	132 GPa

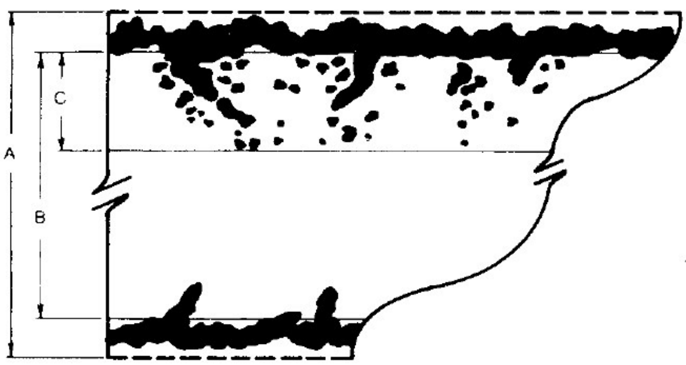
Oxidation Resistance

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	mm
1800	982	**214®**	0.07	0.002	0.20	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	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	0.160
		600	0.32	0.008	0.90	0.023	7.8	0.198
		X	0.34	0.009	0.94	0.024	8.2	0.208
		556®	0.39	0.010	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	0.279
		S	**0.44**	**0.011**	**1.29**	**0.033**	**11.2**	**0.285**
		310 SS	0.97	0.023	1.30	0.033	11.3	0.287
		188	0.43	0.010	1.33	0.033	11.6	0.290
		600	1.10	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	4.80	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	0.760
		310 SS	2.97	0.075	4.44	0.113	38.6	0.980
		X	4.50	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	77.0	1.956
		556®	9.31	0.237	11.64	0.296	101.2	2.571
		625	15.96	0.405	18.20	0.462	158.2	4.018

*Cycled to room temperature once a week

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	Metal	Maximum	Total Metal

Test Temperature		Period	Loss/Slide		Penetration Side		Affected/Side	
°F	°C	h	mils	mm	mils	mm	mils	mm
1600	871	100	1.0	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	0.10

*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 <500ºF (<260ºC) 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 <500ºF (<260ºC) 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/Slide		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	0.10	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	0.10	4.3
304 SS	8.4	0.21	9.8

Comparative Carburization Resistance

1800ºF for 55 Hours in 5%CO-5%CH_4-5%H_2-Ar

Alloy	Carbon Absorption (mg/cm^2)
214®	0.6
S	**2.1**
230®	2.5
X	2.5
310 SS	3.3
601	4.8

Comparative Molten Chloride Salt Resistance

1550ºF 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	115	2.92

Hardness

Room Temperature*

Form	Aging Temperature °F	Aging Temperature °C	Aging Time h	Hardness HRA
Sheet	Solution-annealed		-	52
	1000	538	1000	64
			4000	66
			8000	65
			16000	67
	1200	649	1000	56
			4000	55
			8000	56
			16000	55
	1400	760	1000	54
			4000	54
			8000	53
			16000	54
Plate	Solution-annealed		-	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-annealed		-	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

Tensile Data

Form	Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
	°F	°C	ksi	MPa	ksi	MPa	%
Sheet 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	16.0	110	28.0	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	118.0	814	60
	400	204	48.0	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	41.0	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	33.0	228	62
	2000	1093	8.8	61	17.0	117	69

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

RT=Room Temperature

Average 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	%
Sheet 0.057 in (1.45 mm) thick	Solution-annealed		-	128.6	887	63.0	434	58
	1000	538	1000	178.6	1231	109.2	753	45
			4000	181.7	1253	107.5	741	41
			8000	185.1	1276	119.1	821	41
			16000	186.8	1288	120.5	831	38
	1200	649	1000	133.4	920	69.3	478	56
			4000	130.3	898	66.3	457	52
			8000	132.5	914	65.9	454	54
			16000	133.1	918	68.4	472	50
	1400	760	1000	133.3	919	66.6	459	54
			4000	132.2	910	64.9	447	51
			8000	131.1	904	65.3	450	54
			16000	128.3	885	62.6	432	52
Plate ½ in (12.7 mm) thick	Solution Heat-Treated		-	125.3	864	52.9	365	54
	800	427	1000	125.7	867	55.9	385	60
			4000	126.9	875	55.5	383	60
			8000	126.7	874	56.6	390	55
			16000	128.0	883	57.9	399	56
	1000	538	1000	144.4	996	71.5	493	46
			4000	175.0	1207	102.5	707	44
			8000	180.8	1247	108.2	746	38
			16000	182.5	1258	108.9	751	39
	1200	649	1000	125.1	863	56.6	390	57
			4000	125.8	867	56.4	389	54
			8000	127.2	877	57.0	393	50
			16000	127.9	882	59.3	409	49
	1400	760	1000	126.0	869	53.7	370	55
			4000	127.4	878	54.1	373	52
			8000	127.5	879	53.5	369	46
			16000	127.5	879	53.9	372	47
	1600	871	1000	125.8	867	50.8	350	58
			4000	125.2	863	50.7	350	56
			8000	123.5	852	51.3	354	53
			16000	123.3	850	50.5	348	56

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

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-annealed		-	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-annealed		-	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 Data

Average 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	50.0	345	38.0	262
1350	732	39.0	269	28.2	194	20.2	139
1500	816	23.5	162	15.0	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

Average Rupture Data, 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	80.0	552	58.0	400	27.0	186
1300	704	56.0	386	38.0	262	16.0	110
1400	760	38.0	262	24.5	169	9.8	68
1500	816	25.0	172	16.0	110	5.8	40
1600	871	16.5	114	9.8	68	3.0	21

*1-in. (25.4mm) thick plate

Average 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	45.0	310	31.5	217	21.0	145
		0.5	50.0	345	35.5	245	24.0	165
		1.0	56.5	390	40.0	276	27.0	186
1350	732	0.2	22.0	152	14.1	97	9.0	62
		0.5	25.0	172	16.2	112	10.4	72
		1.0	29.0	200	19.0	131	12.2	84
1500	816	0.2	10.2	70	5.9	41	-	-
		0.5	11.8	81	7.0	48	-	-
		1.0	13.8	95	8.4	58	-	-

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

Average Creep Data, 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	45.0	310	27.0	186	17.0**	117**	-	-
		0.5	54.0	372	32.6	255	19.0	131	-	-
		1.0	56.0	386	34.0	234	20.8	143	13.5	93
1300	704	0.2	24.0	165	12.5	86	6.7**	46**	-	-
		0.5	29.0	200	16.5	114	9.0	62	-	-
		1.0	34.0	234	20.0	138	12.0	83	7.2	50
1400	760	0.2	13.0	90	6.5	45	3.3**	23**	-	-
		0.5	16.9	117	9.2	63	4.8	33	-	-
		1.0	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	10.0	69	5.7	39	3.0	21	-	-
		1.0	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	-	-
		1.0	7.6	52	4.1	28	2.2	15	1.1	8

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

Disclaimer