HAYNES® 188 alloy

Principal Features

Excellent High-Temperature Strength and Environment Resistance

HAYNES® 188 alloy (UNS R30188) is a cobalt-nickel-chromium-tungsten alloy that combines excellent high-temperature strength with very good resistance to oxidizing environments up to 2000°F (1095°C) for prolonged exposures, and excellent resistance to sulfate deposit hot corrosion. It is readily fabricated and formed by conventional techniques, and has been used for cast component. Other attractive features include excellent resistance to molten chloride salts, and good resistance to gaseous sulfidation.

Readily Fabricated

HAYNES® 188 alloy has good forming and welding characteristics. It may be forged or other hot-worked, providing that it is held at 2150°F (1175°C) for a time sufficient to bring the entire piece to temperature. As a consequence of its good ductility, 188 alloy is also readily formed by cold working. The alloy does work-harden rapidly, however, so frequent intermediate annealing treatments may be needed for complex component forming operations. All hot- or cold- worked parts should be annealed and rapidly cooled in order to restore the best balance of properties.

The alloy can be welded by both manual and automatic welding methods, including gas tungsten arc (TIG), gas metal arc (MIG), electron beam and resistance welding. It exhibits good restraint welding characteristics.

Heat Treatment

Wrought HAYNES® 188 alloy is furnished in the solution heat treated condition, unless otherwise specified. The alloy is normally solution heat-treated at 2125-2175°F (1163-1191°C) and rapidly cooled or water quenched for optimal properties.

Annealing at temperatures less than the solution heat-treating temperature will produce some carbide precipitation in alloy 188, which may affect the alloy's properties.

Applications

HAYNES® 188 alloy combines properties which make is suitable for a variety of fabricated component applications in the aerospace industry. It is widely used in established military and commercial gas turbine engines for combustion cans, transitions ducts, and afterburner components. It shares applications in newer engine programs with a more recently developed material, 230® alloy, which possesses improved properties.

The F-15 Eagle has broken nearly every existing aircraft rate-of-climb record. HAYNES® 188 alloy helped generate the extra power by permitting a 300°F higher combustor operating temperature.

Nominal Composition

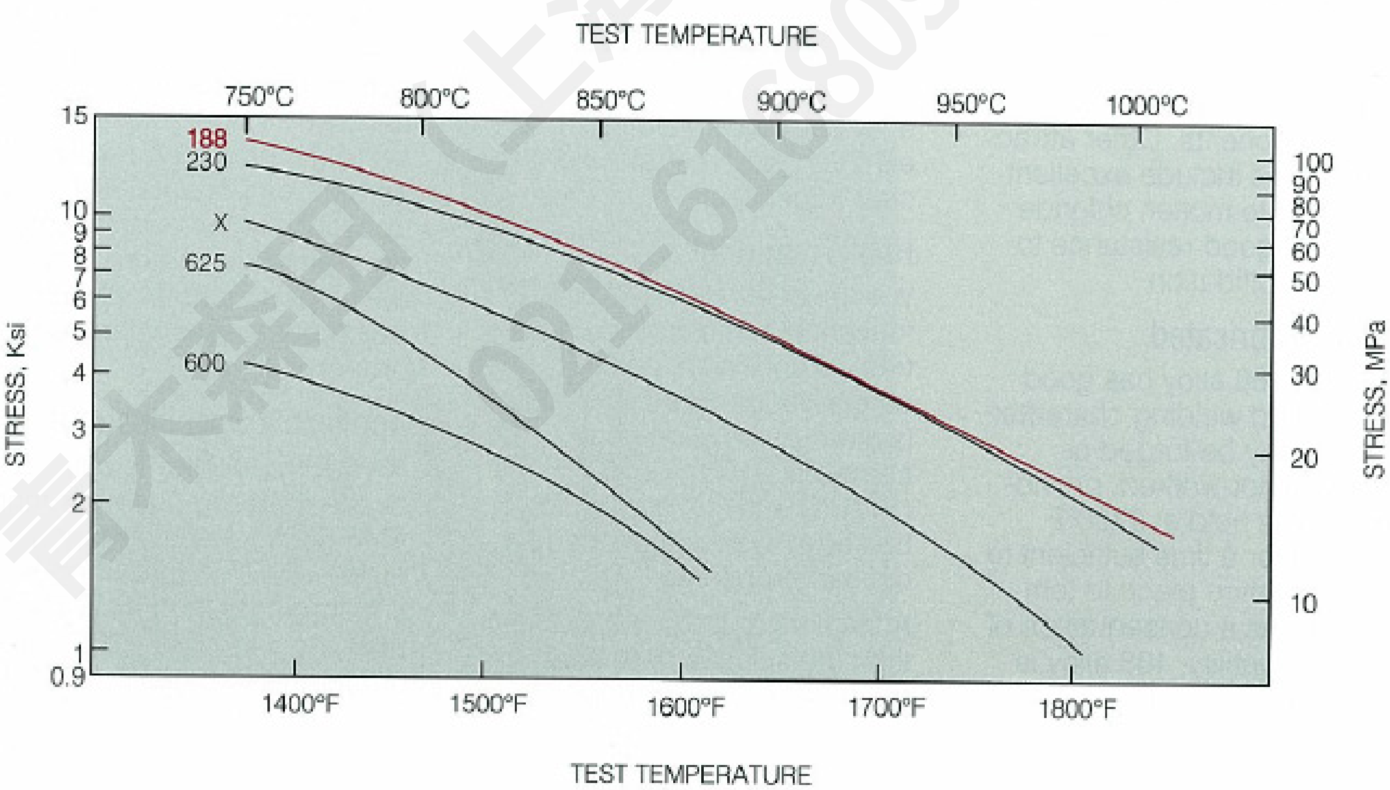
Weight, %

Cobalt:	39 Balance
Nickel:	22
Chromium:	22
Tungsten:	14
Iron:	3 max.
Manganese:	1.25 max.
Silicon:	0.35
Carbon:	0.10
Lanthanum:	0.03
Boron:	0.015 max.

Creep and Stress-Rupture Strength

HAYNES® 188 alloy is a solid-solution- strengthened material which combines excellent high-temperature strength with good fabricability at room temperature. It is particularly effective for very long-term applications at temperatures of 1200°F (650°C) or more. It is stronger than nickel-base solid-solution-strengthened alloys, and far stronger than simple nickel chromium or iron-nickel-chromium heat-resistant alloys. This can allow for significant section thickness reduction when it is substituted for these materials.

Comparision of Sheet Materials: Stress to Produce 1% Creep in 1000 Hours



Creep and Stress-Rupture Strength Continued

188 Plate, Solution Annealed

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	0.5	--	--	--	--	--	--	--	--
		1	--	--	--	--	35*	241*	--	--
		R	--	--	78	538	59	407	45*	310*
1300	704	0.5	41	283	28	193	18*	124*	--	--
		1	44	303	31.5	217	22	152	--	--
		R	73*	503*	54	372	40	276	28	193
1400	760	0.5	26	179	17	117	11.5	79	--	--
		1	29	200	20.5	141	14.5*	100*	--	--
		R	51	352	37	255	26	179	18.5*	128*
1500	816	0.5	16	110	11	76	7.7*	53*	--	--
		1	19	131	13.5	93	9.3	64	--	--
		R	36	248	25	172	17.5	121	12	83
1600	871	0.5	11.5	79	7.5	52	5.5*	38*	--	--
		1	13	90	9	62	6.4*	44*	--	--
		R	25	172	17	117	11.6	80	7.8	54
1700	927	0.5	8	55	5.2	36	3.6*	25*	--	--
		1	9.2	63	6	41	4.3*	30*	--	--
		R	16.5	114	11.1	77	7.3	50	4.5*	31*
1800	982	0.5	5.6	39	3.6	25	2.3	16	1.35	9.3
		1	6.3	43	4.2	29	2.5	17	1.42	9.8
		R	11.5	79	7	48	4	28	2.2*	15*
1900	1038	0.5	3.7	26	2.3*	16*	--	--	--	--
		1	4.2	29	2.5*	17*	--	--	--	--
		R	7.2*	50*	4.4	30	2.2*	15*	--	--
2000	1093	0.5	2.3	16	1.35	9.3	--	--	--	--
		1	2.6	18	1.42	9.8	--	--	--	--
		R	4.7	32	2.3	16	1.10*	7.6*	--	--

*Significant extrapolation

Creep and Stress-Rupture Strength Continued

188 Sheet, Solution Annealed

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
1400	760	0.5	22.5	155	16.4	113	11.7	81
		1	25.5	176	18.5	128	13.3	92
		R	43.0*	296*	32	221	23	159
1500	816	0.5	15.5	107	11.1	77	7.8	54
		1	17.6	121	12.6	87	8.8	61
		R	31	214	21.7	150	15	103
1600	871	0.5	10.7	74	7.5	52	5	34
		1	12.2	84	8.4	58	5.7	39
		R	21	145	14.4	99	9.4	65
1700	927	0.5	7.3	50	4.9	34	3.1	21
		1	8.2	57	5.6	39	3.6	25
		R	14.3	99	9.1	63	5.5*	38*
1800	982	0.5	4.9	34	3.1	21	1.8	12
		1	5.6	39	3.6	25	2.1	14
		R	9.1	63	5.4	37	3	21
1900	1038	0.5	3.1	21	1.9	13	1.2	8.3
		1	3.6	25	2.2	15	1.4	9.7
		R	5.5	38	3.2	22	2	14
2000	1093	0.5	2.0*	14*	1.2	8.3	0.7	4.8
		1	2.3*	16*	1.4	9.7	0.9	6.2
		R	3.3*	23*	2	14	1.2	8.3

*Significant extrapolation

Tensile Properties

Hot-Rolled and Solution-Annealed Plate

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	70.1	483	143.8	991	50.6
1000	538	45.7	315	120.6	832	60.3
1200	649	45.1	311	121.6	838	62.8
1400	760	43.6	301	84.1	580	85.6
1600	871	37.1	256	49.5	341	97.9
1800	982	19.2	132	27.2	188	102.6
2000	1093	9.6	66	13.9	96	87.1

Cold-Rolled and Solution-Annealed Sheet

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	70.1	483	142.4	982	50.9
1000	538	44.8	309	117.4	809	58.8
1200	649	44.8	309	119.1	821	58.6
1400	760	43.8	302	81.6	563	81.8
1600	871	37.8	261	47.0	324	103.9
1800	982	18.2	125	25.4	175	81.0
2000	1093	8.5	59	12.4	85	49.7

RT= Room Temperature

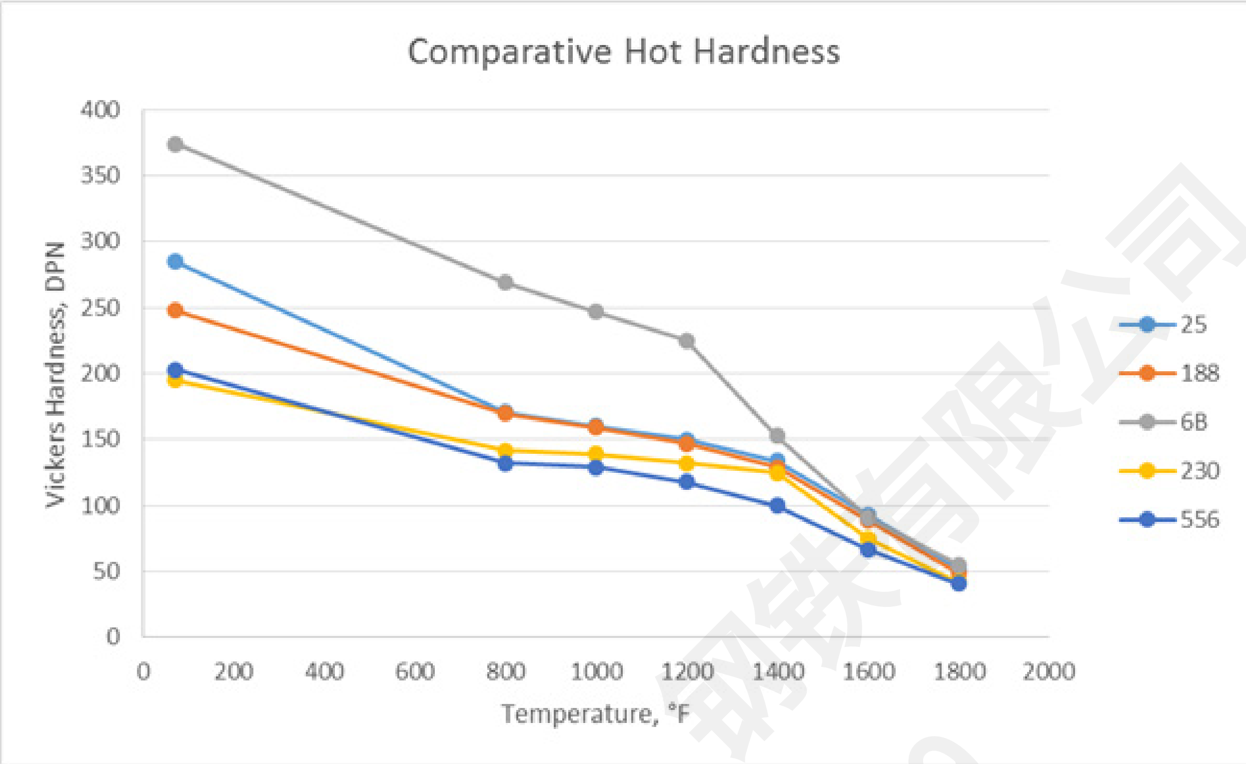
Hardness Data

Solution Annealed Room Temperature Hardness

Form	Hardness, HRB	Typical ASTM Grain Size
Sheet	98	5 - 7.5
Plate	98	4 - 8
Bar	96	3.5 - 7.5

All samples tested in solution-annealed condition
HRB = Hardness Rockwell "B"

High-Temperature Hardness



Temperature		188		25		6B		230®		556®	
		Vickers Hardness	Rockwell Hardness	Vickers Hardness	Rockwell Hardness	Vickers Hardness	Rockwell Hardness	Vickers Hardness	Rockwell Hardness	Vickers Hardness	Rockwell Hardness
°F	°C	DPN	HR C/B	DPN	HR C/B	DPN	HR C/B	DPN	HR C/B	DPN	HR C/B
72	RT	**248**	**21.8 C**	285	27.8 C	374	38.2 C	195	92.0 B	203	93.6 B
800	427	**170**	**86.3 B**	171	86.7 B	269	25.5 C	142	77.3 B	132	73.0 B
1000	538	**159**	**83.0 B**	160	73.3 B	247	21.8 C	139	76.0 B	129	71.1 B
1200	649	**147**	**77.2 B**	150	80.0 B	225	97.5 B	132	73.0 B	118	66.5 B
1400	760	**129**	**70.7 B**	134	73.7 B	153	81.0 B	125	70.0 B	100	55.0 B
1600	871	**89**	**-**	93	-	91	-	75	-	67	-
1800	982	**49**	**-**	52	-	55	-	42	-	41*	-

HRB = Hardness Rockwell "B"
HRC = Hardness Rockwell "C"

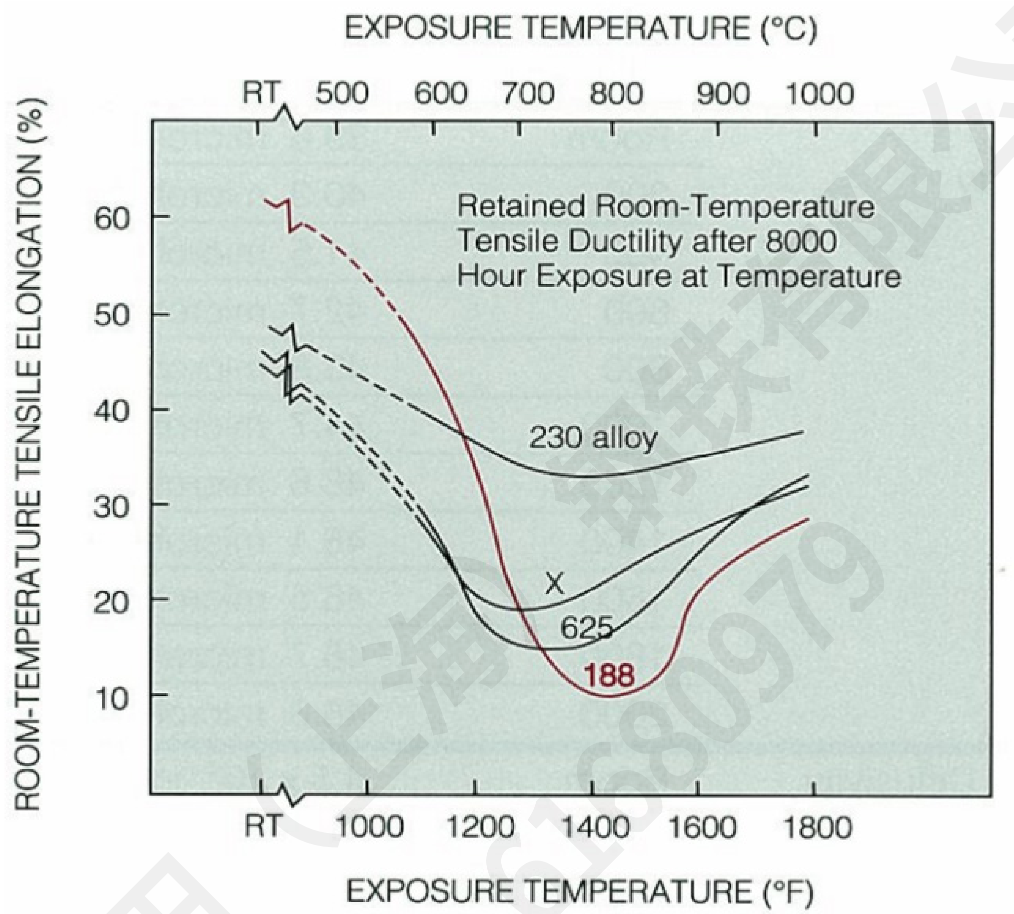
Impact Strength

Test Temperature		Typical Charpy V-Notch Impact Resistance	
°F	°C	ft.-lbs	J
-300	-185	116	158
-150	-100	131	178
70	20	143	194
1000	540	117	159
1300	705	107	145

*Average of longitudinal and transverse tests on solution-annealed plate

Thermal Stability

HAYNES® 188 alloy is similar to the solid-solution-strengthened superalloys, such as alloy 625 or HASTELLOY® X alloy, which will precipitate deleterious phases upon such long-ter m exposure. In this case. the phase in question is a Co_2W laves phase. which serves to impair both tensile ductility and impact strength. The behavior of 188 alloy is significantly bet- ter in this regard than HAYNES® 25 alloy, which it replaced; but for applications where thermal stability is important, 230® alloy is recommended.



Room-Temperature Properties of Plate after Thermal Exposure

Exposure Temperature		-	0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Impact Strength	
°F	°C	h	ksi	MPa	ksi	MPa	%	ft.- lbs.	J
1200	650	0	65	450	140	965	56	143	194
		8000	79.7	550	151.6	1045	29.1	23	31
1400	760	0	65	450	140	965	56	143	194
		8000	74	510	147.9	1020	10.8	3	4
1600	870	0*	70.1	485	146	1005	50.4	143	194
		1000	70.7	490	157.5	1085	28.7	10	13
		4000	68.8	475	156	1075	26.6	10	13
		8000*	64.5	445	147.4	1015	22.2	9	12
		16000	63.8	440	146.1	1005	24	8	11

*Average of two test exposure. All other single exposures.

Thermal Stability Continued

Comparative Impact Strength after 8000-Hour Exposures

Alloy	Solution-Annealed Charpy V-Notch Impact		Charpy V-Notch Impact Following Exposure For 8000 Hours at Temperatures					
			1200°F	650°C	1400°F	760°C	1600°F	870°C
-	ft.-lbs.	J	ft.-lbs	J	ft.-lbs	J	ft.-lbs	J
230®	54	73	30	41	21	28	21	28
188	**143**	**194**	**23**	**31**	**3**	**4**	**9**	**12**
X	54	73	15	20	8	11	15	20
625	81	110	5	7	5	7	15	20

Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.24 lb/in^3	RT	8.98 g/cm^3
Melting Temperature	2400-2570°F	-	1315-1410°C	-
Electrical Resistivity	RT	39.6 µohm-in	RT	101.0 µohm-cm
	200°F	40.3 µohm-in	100°C	103.0 µohm-cm
	400°F	41.5 µohm-in	200°C	105.0 µohm-cm
	600°F	42.7 µohm-in	300°C	107.7 µohm-cm
	800°F	43.8 µohm-in	400°C	110.5 µohm-cm
	1000°F	44.7 µohm-in	500°C	112.7 µohm-cm
	1200°F	45.6 µohm-in	600°C	114.8 µohm-cm
	1400°F	46.1 µohm-in	700°C	116.4 µohm-cm
	1600°F	46.5 µohm-in	800°C	117.5 µohm-cm
	1800°F	46.7 µohm-in	900°C	118.3 µohm-cm
	2000°F	46.8 µohm-in	1000°C	119.1 µohm-cm
Specific Heat	RT	0.096 Btu/lb-°F	RT	12.1 J/kg·°C
	200°F	0.101 Btu/lb-°F	100°C	423 J/kg·°C
	400°F	0.106 Btu/lb-°F	200°C	444 J/kg·°C
	600°F	0.112 Btu/lb-°F	300°C	465 J/kg·°C
	800°F	0.117 Btu/lb-°F	400°C	486 J/kg·°C
	1000°F	0.122 Btu/lb-°F	500°C	502 J/kg·°C
	1200°F	0.127 Btu/lb-°F	600°C	523 J/kg·°C
	1400°F	0.131 Btu/lb-°F	700°C	540 J/kg·°C
	1600°F	0.136 Btu/lb-°F	800°C	557 J/kg·°C
	1800°F	0.140 Btu/lb-°F	900°C	573 J/kg·°C
	2000° F	0.145 Btu/lb-°F	1000°C	590 J/kg·°C

RT= Room Temperature

Physical Properties Continued

Physical Property	British Units		Metric Units	
Thermal Conductivity	RT	72 Btu-in/ft^2-hr-°F	RT	10.4 W/m-°C
	200°F	84 Btu-in/ft^2-hr-°F	100°C	12.2 W/m-°C
	400°F	100 Btu-in/ft^2-hr-°F	200°C	14.3 W/m-°C
	600°F	112 Btu-in/ft^2-hr-°F	300°C	15.9 W/m-°C
	800°F	125 Btu-in/ft^2-hr-°F	400°C	17.5 W/m-°C
	1000°F	138 Btu-in/ft^2-hr-°F	500°C	19.3 W/m-°C
	1200°F	152 Btu-in/ft^2-hr-°F	600°C	21.1 W/m-°C
	1400°F	167 Btu-in/ft^2-hr-°F	700°C	23.0 W/m-°C
	1600°F	174 Btu-in/ft^2-hr-°F	800°C	24.8 W/m-°C
	1800°F	189 Btu-in/ft^2-hr-°F	900°C	25.5 W/m-°C
	2000°F	204 Btu-in/ft^2-hr-°F	1000°C	27.6 W/m-°C
Thermal Diffusivity	RT	4.5 x 10^{-3} in^2/sec	RT	29.2 x $10^{-3}$$cm^2$/s
	200°F	5.0 x 10^{-3} in^2/sec	100°C	32.7 x $10^{-3}$$cm^2$/s
	400°F	5.6 x 10^{-3} in^2/sec	200°C	36.5 x $10^{-3}$$cm^2$/s
	600°F	6.0 x 10^{-3} in^2/sec	300°C	38.7 x $10^{-3}$$cm^2$/s
	800°F	6.4 x 10^{-3} in^2/sec	400°C	40.8 x $10^{-3}$$cm^2$/s
	1000°F	6.7 x 10^{-3} in^2/sec	500°C	43.5 x $10^{-3}$$cm^2$/s
	1200°F	7.1 x 10^{-3} in^2/sec	600°C	45.7 x $10^{-3}$$cm^2$/s
	1400°F	7.6 x 10^{-3} in^2/sec	700°C	48.2 x $10^{-3}$$cm^2$/s
	1600°F	7.6 x 10^{-3} in^2/sec	800°C	50.4 x $10^{-3}$$cm^2$/s
	1800°F	8.0 x 10^{-3} in^2/sec	900°C	50.4 x $10^{-3}$$cm^2$/s
	2000°F	8.4 x 10^{-3} in^2/sec	1000°C	53.0 x $10^{-3}$$cm^2$/s
Mean Coefficient of Thermal Expansion	75-200°F	6.7 10^{-6}in/in/°F	25-100°C	12.1 10^{-6} m/m/°C
	75-400°F	7.1 10^{-6}in/in/°F	25-200°C	12.7 10^{-6} m/m/°C
	75-600°F	7.3 10^{-6}in/in/°F	25-300°C	13.1 10^{-6} m/m/°C
	75-800°F	7.6 10^{-6}in/in/°F	25-400°C	13.5 10^{-6} m/m/°C
	75-1000°F	7.7 10^{-6}in/in/°F	25-500°C	13.9 10^{-6} m/m/°C
	75-1200°F	8.2 10^{-6}in/in/°F	25-600°C	14.3 10^{-6} m/m/°C
	75-1400°F	8.5 10^{-6}in/in/°F	25-700°C	15.0 10^{-6} m/m/°C
	75-1600°F	8.8 10^{-6}in/in/°F	25-800°C	15.5 10^{-6} m/m/°C
	75-1800°F	9.1 10^{-6}in/in/°F	25-900°C	16.0 10^{-6} m/m/°C
	-	-	25-1000°C	16.5 10^{-6} m/m/°C

RT= Room Temperature

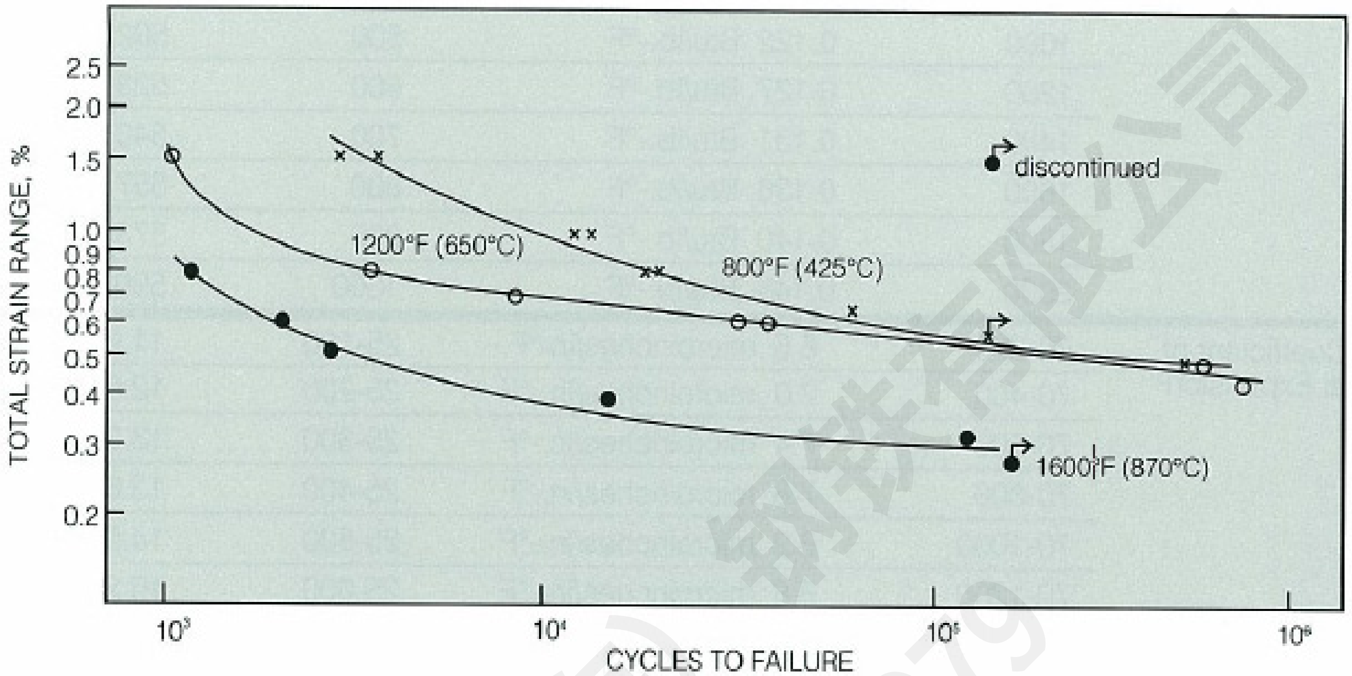
Physical Properties Continued

Physical Property	Metric Units		British Units	
Dynamic Modulus of Elasticity	RT	33.7 x 10^6 psi	RT	232 GPa
	200°F	32.9 x 10^6 psi	100°C	226 GPa
	400°F	31.8 x 10^6 psi	200°C	220 GPa
	600°F	30.8 x 10^6 psi	300°C	213 GPa
	800°F	29.5 x 10^6 psi	400°C	206 GPa
	1000°F	28.6 x 10^6 psi	500°C	198 GPa
	1200°F	27.1 x 10^6 psi	600°C	189 GPa
	1400°F	25.6 x 10^6 psi	700°C	180 GPa
	1600°F	24.0 x 10^6 psi	800°C	171 GPa
	1800°F	22.2 x 10^6 psi	900°C	160 GPa
	2000°F	20.2 x 10^6 psi	1000°C	150 GPa
Dynamic Shear Modulus	RT	13.0 x 10^6 psi	RT	90 GPa
	400°F	12.5 x 10^6 psi	100°C	88 GPa
	600°F	12.0 x 10^6 psi	200°C	86 GPa
	800°F	11.4 x 10^6 psi	300°C	83 GPa
	1000°F	10.9 x 10^6 psi	400°C	80 GPa
	1200°F	10.3 x 10^6 psi	500°C	76 GPa
	1400°F	9.7 x 10^6 psi	600°C	73 GPa
	1600°F	9.0 x 10^6 psi	700°C	69 GPa
	1800ºF	8.3 x 10^6 psi	800ºC	65 GPa
	2000°F	7.5 x 10^6 psi	900°C	61 GPa
	-	-	1000ºC	56 GPa
Poisson's Ratio	RT°F	0.3	RT	0.3
	200°F	0.29	100°C	0.29
	400°F	0.27	200°C	0.27
	600°F	0.29	300°C	0.29
	800°F	0.29	400°C	0.29
	1000°F	0.31	500°C	0.3
	1200°F	0.32	600°C	0.31
	1400°F	0.32	700°C	0.32
	1600°F	0.33	800°C	0.32
	1800°F	0.33	900°C	0.33
	2000°F	0.34	1000°C	0.33

RT= Room Temperature

Low Cycle Fatigue Properties

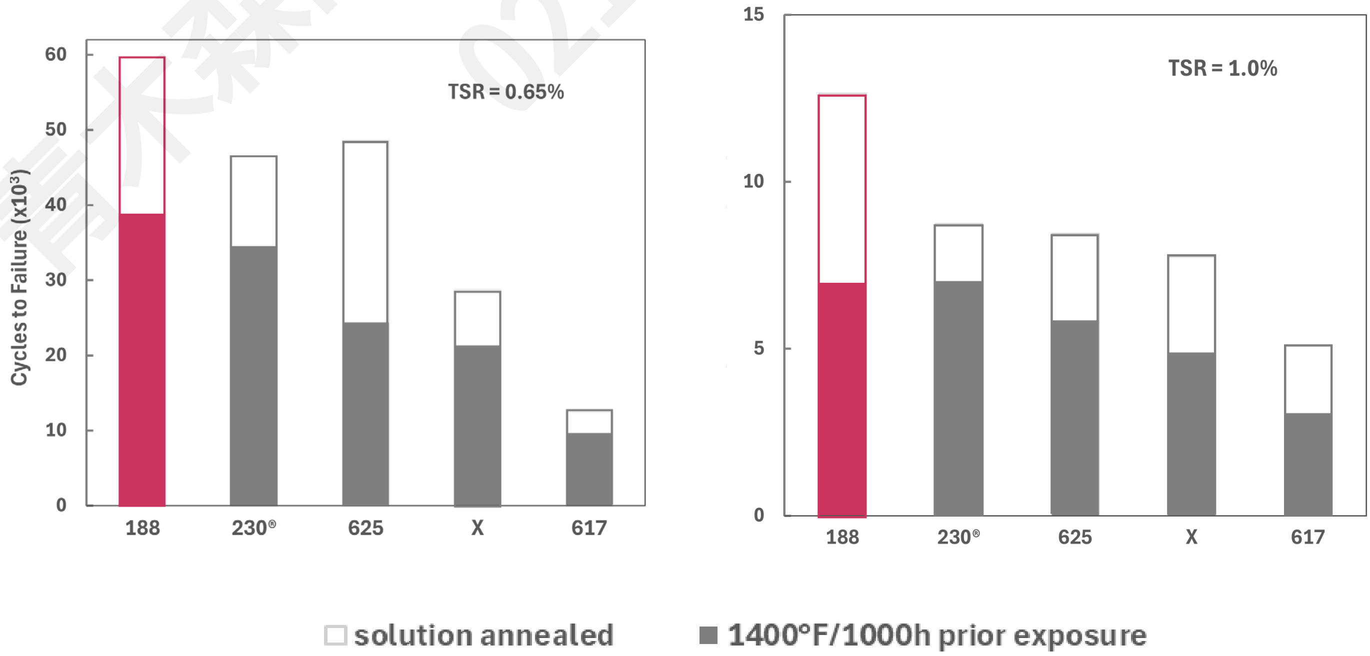
HAYNES® 188 alloy exhibits very good low cycle fatigue properties at elevated temperatures. Results shown below are for strain-controlled tests run in the temperature range from 800°F (425°C) to 1600°F (870°C). Samples were machined from bar. Tests were run with fully reversed strain (R = -1) at a frequency of 20 cpm (0.33 Hz).



Comparative Low-Cycle Fatigue Porperties

The graph below shows the effect of thermal exposure on the low cycle fatigue lives of several solid solution strengthened alloys. Samples were tested at 800°F (427°C) in both solution annealed and 1400°F (760°C)/1000hour pre-exposed condition. Samples were machined from plate or bar, after exposure for exposed samples. Tests were run with fully reversed strain (R=-1) at a frequency of 20 cpm (0.33 Hz). TSR=Total Strain Range.

800°F (425°C) LCF Life for Various Alloys



Oxidation Resistance

HAYNES® 188 alloy exhibits very good resistance to both air and combustion gas oxidizing environments, and can be used for long-term continuous exposure at temperatures up to 2000°F (1095°C). For exposures of short duration, 188 alloy can be used at higher temperatures.

Comparative Oxidation Resistance in Flowing Air*

	1800°F (980°C)				2000°F (1095°C)				2100°F (1150°C)			
	Average Metal Affected**		Metal Loss		Average Metal Affected**		Metal Loss		Average Metal Affected**		Metal Loss	
Alloy	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm
188	**1.1**	**28**	**0.1**	**3**	**3.7**	**94**	**0.5**	**13**	**10.7**	**272**	**8.6**	**218**
230®	1.5	38	0.2	5	3.3	84	0.5	13	4.4	112	1.2	30
X	1.5	38	0.2	5	4.4	112	1.3	33	6.1	115	3.6	91
625	1.9	48	0.4	10	7.8	198	3.5	89	20.2	513	18.3	465
617	2	51	0.3	8	3.8	97	0.6	15	5.2	132	1	25

*Flowing air at a velocity of 7.0 ft/min (213.4 cm/min) past the samples. Samples cycled to room temperature once per week.
**Metal Loss + Average Internal Penetration

Oxidation Test Parameters

Burner rig oxidation tests were conducted by exposing samples 3/8 in. x 2.5 in. x thickness (9 mm x 64 mm x thickness), in a rotating holder, to products of combustion of No. 2 fuel oil burned at a ratio of air to fuel of about 50:1. (Gas velocity was about 0.3 mach). Samples were automatically removed from the gas stream every 30 minutes and fan-cooled to near ambient temperature and then reinserted into the flame tunnel.

Comparative Burner Rig Oxidation Resistance 1000 Hour Exposure at 1800°F (980°C)

1000 Hour Exposure at 1800°F (980°C), 30 Minute Cycles						
	Metal Loss		Average Metal Affected		Maximum Metal Affected	
Alloy	mils	µm	mils	µm	mils	µm
188	**1.1**	**28**	**3.2**	**81**	**3.9**	**99**
230®	2.8	71	5.6	142	6.4	163
617	2.4	61	5.7	145	6.9	175
625	3.7	94	6	152	6.6	168
X	4.3	109	7.3	185	8	203

Oxidation Resistance Continued

Comparative Burner Rig Oxidation Resistance at 2000°F (1095°C) for 500 Hours

500 Hour Exposure at 2000°F (1095°C), 30 Minute Cycles						
	Average Metal Loss Per Side		Average Metal Affected		Maximum Metal Affected	
Alloy	mils	µm	mils	µm	mils	µm
230®	7.1	180	9.9	251	11.8	300
188	**10.9**	**277**	**13.1**	**333**	**14.1**	**358**
X	11.6	295	14	356	15.1	384
617	13.3	338	20.9	531	21.2	538
625	Consumed					

Water Vapor Oxidation Data

Air + 20% H_2O at 1800°F (982°C), 1008 hours, cycled weekly				
	Metal Loss		Average Metal Affected	
Alloy	mils	µm	mils	µm
214®	0.04	1	0.64	16
230®	0.19	5	1.59	40
625	0.36	9	1.66	42
188	**0.18**	**5**	**1.48**	**38**
X	0.27	7	1.77	45
617	0.39	10	1.99	50
556®	0.35	9	1.85	47
HR-120®	0.38	10	2.08	53
800HT	2.47	63	5.07	129
HR-160®	0.77	20	5.57	141

Hot Corrosion Resistance

HAYNES® 188 alloy exhibits excellent resistance to sulfate deposit type hot corrosion. Tests were conducted in a low velocity burner rig burning No. 2 Fuel oil with 0.4 percent sulfur. The air:fuel ratio was 30:1. Artificial sea water was injected at a rate equivalent to 5 ppm salt. Tests were run for 1000 hours, with samples cycled out of the gas stream once an hour and cooled to near ambient temperature. Gas velocity was 13 ft./ sec. (4 m/s).

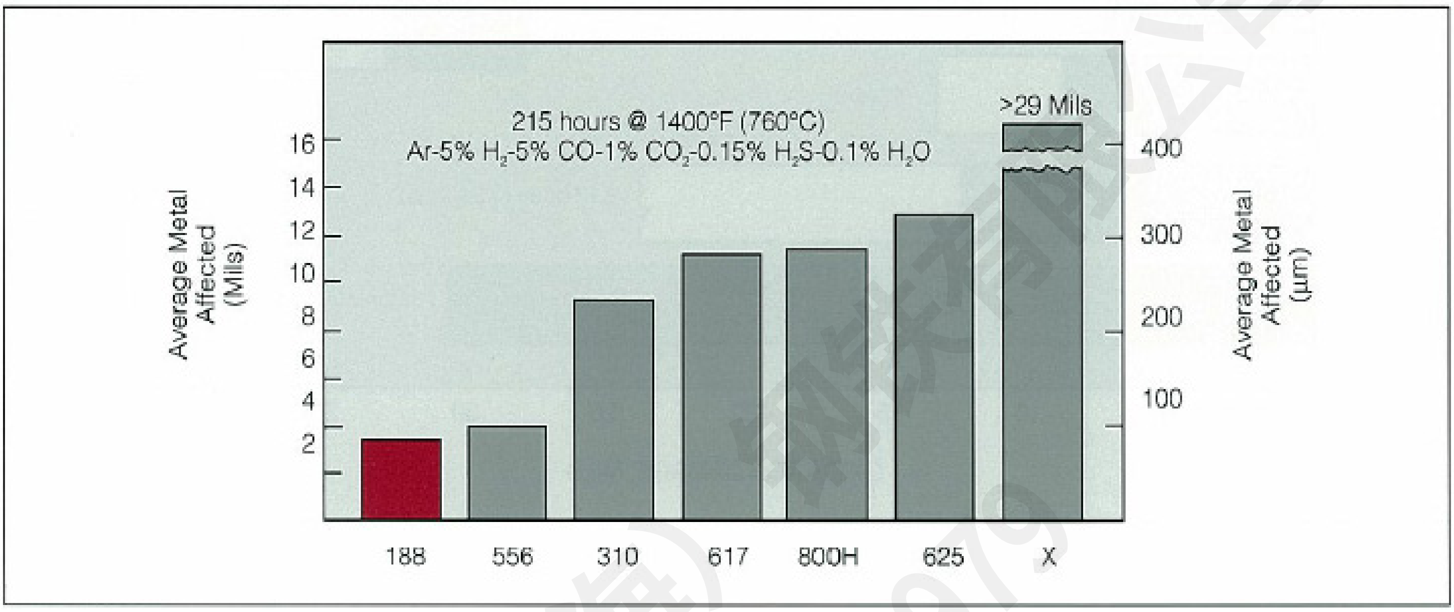
Hot Corrosion Resistance at 1650°F (900°C)

Alloy	Metal Loss		Average Metal Affected	
-	mils	µm	mils	µm
188	**0.8**	**20**	**2.7**	**69**
230®	1.2	30	5.1	130
625	1.8	46	5.2	132
X	1.6	41	5.5	140

Sulfidation Resistance

HAYNES® 188 alloy has very good resistance to gaseous sulfidation envronments encountered in various industrial applications. Tests were conducted at 1400°F (760°C) in a gas mixture consisting of 5 percent H_2, 5 percent CO_1, 1 percent CO_2 , and 0.15 percent H_2S, balance Ar. Coupons were exposed for 215 hours. This is a severe test, with equilibrium sulfur partial pressure of 10^{-6} to 10^{-7} and oxygen partial pressures less than that needed to produce protective chromium oxide scales.

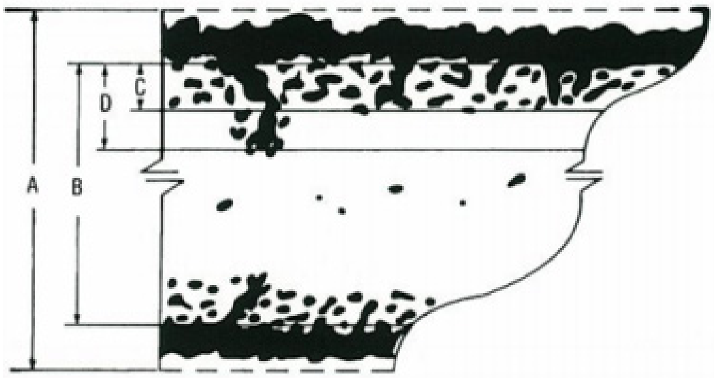
Sulfidation Resistance at 1400°F (760°C)



215 hours in an atmosphere of 5% H_2 + 5% CO + 0.15% H_2S + Balance Ar								
	1400°F (760°C)				1600°F (871°C)			
	Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected	
Alloy	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**
25	0.5	13	1.5	38	1.1	28	5.3	135
188	**1.6**	**41**	**3.3**	**84**	**1.7**	**44**	**5.7**	**145**
556®	3.1	77	4.9	124	6.2	157	16.4	417
310	6.2	157	9.1	231	8.3	211	14.1	358
617	5	127	10.8	274	3.8	97	17.2	437
800H	7.1	180	11.2	284	7.9	201	>27.6	>701
625	6.6	168	12.6	320	Partially Consumed			
X	-	-	>29.5	>749	-	-	>21.7	>551

Sulfidation Resistance Continued

Schematic Representation of Metallographic Technique Used for Evaluating Environmental Tests



1. Metal Loss = (A - B)/2
2. Average Internal Penetration = C
3. Maximum Internal Penetration = D
4. Average Metal Affected = ((A - B)/2) + C
5. Maximum Metal Affected = ((A - B)/2) + D

Fabrication Characteristics

Heat Treatment

HAYNES® 188 alloy is normally final solution heat-treated at 2150°F (1175°C) for a time commensurate with section thickness. Annealing during fabrication can be performed at even lower temperatures, but at a final, subsequent solution heat treatment is needed to produce optimum properties and structure. Please call Haynes International for further information.

Effect of Cold Reduction Upon Room-Temperature Properties*

Cold Reduction	Subsequent Temperature	0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Hardness
%	-	ksi	MPa	ksi	MPa	%	HR B/C
0	NONE	66.9	460	137.2	945	54.2	98.1 HRB
10		105.9	730	151.5	1045	45.1	32.1 HRC
20		132.9	915	165.9	1145	28.3	37.1 HRC
30		167	1150	195.1	1345	13.4	41.2 HRC
40		176.8	1220	214.9	1480	9.8	43.5 HRC
10	1950°F (1065°C) For 5 min.	91.2	630	148.5	1025	41.4	29.7 HRC
20		87.8	605	153.3	1055	41	27.8 HRC
30		84.2	580	158.3	1090	41.3	29.6 HRC
40		90.8	625	162.7	1120	39.8	31.1 HRC
10	2050°F (1120°C) For 5 min.	64.7	445	143	985	50.1	21.9 HRC
20		71.4	490	149	1025	47.2	24.5 HRC
30		80.3	555	155.2	1070	43.7	27.6 HRC
40		86.9	600	159	1095	43.2	29.5 HRC
10	2150°F (1175°C) For 5 min.	61.9	425	139.6	965	55.3	95.6 HRB
20		64.9	445	141.3	975	53.3	97.1 HRB
30		66.5	460	142.8	985	51.8	98.5 HRB
40		64.1	440	141.5	975	55.5	97.2 HRB

*Based upon rolling reduction taken upon 0.125 in. (3.2 mm) thick sheet. Duplicate tests.
HRC = Hardness Rockwell "C".
HRB = Hardness Rockwell "B".

Welding

HAYNES® 188 alloy is readily welded by Gas Tungsten Arc (TIG), Gas Metal Arc (MIG), Shielded Metal Arc (coated electrodes), electron beam welding and resistance welding techniques. Its welding characteristics are similar to those for HAYNES® 25 alloy. 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. These factors can increase weld restraint and promote cracking.

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. Contact with copper or copper-bearing materials in the joint area should be avoided. It is preferable, but not necessary, that the alloy be in the solution-annealed conditionwhen welded.

Filler Metal Selection
Matching composition filler metal is recommended for joining 188 alloy. For joining section thicknesses greater than 3/8 in. (9.5 mm) 230-W® filler wire is suggested. For shielded metal arc welding, HAYNES® 25 alloy electrodes (AMS 5796) are suggested. For dissimilar metal joining of 188 alloy to nickel-, cobalt- or iron base materials, 188 alloy itself, 230-W filler wire, 556® alloy, HASTELLOY® S alloy (AMS 5838) or HASTELLOY® W alloy (AMS 5786, 5787) welding products are suggested, depending upon the particular case.

Preheating, Interpass Temperatures and Post-Weld Heat Treatment
Preheat is not usually required so long as base metal to be welded is above 32°F (0°C). Interpass temperatures generally should be low. 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 188 alloy. For further information, please contact Haynes International.

Machining

For more information on maching for High-temperature alloys, please visit our website at haynesintl.com/alloys/technical-literature-list.

Specifications and Codes

Specifications

HAYNES® 188 alloy (R30188)	
Sheet, Plate & Strip	AMS5608
Billet, Rod & Bar	AMS 5772
Coated Electrodes	-
Bare Welding Rods & Wire	-
Seamless Pipe & Tube	-
Welded Pipe & Tube	-
Fittings	-
Forgings	AMS 5772
DIN	-
Others	

Codes

HAYNES® 188 alloy (R30188)	
MMPDS	6.4.2