HAYNES® 230® alloy

Principal Features

Excellent High-Temperature Strength, Thermal Stability, and Environment Resistance

HAYNES® 230® (UNS N06230) alloy is a nickel-chromium-tungsten-molybdenum alloy that combines excellent high-temperature strength, outstanding resistance to oxidizing environments up to 2100°F (1149°C) for prolonged exposures, premier resistance to nitriding environments, and excellent long-term thermal stability. It is readily fabricated and formed, and is castable. Other attractive features include lower thermal expansion characteristics than most high-temperature alloys, and a pronounced resistance to grain coarsening with prolonged exposure to high temperatures.

Easily Fabricated

HAYNES® 230® alloy has excellent forming and welding characteristics. It may be forged or otherwise hot-worked, providing it is held at 2150°F (1177°C) for a time sufficient to bring the entire piece to temperature. As a consequence of its good ductility, 230® alloy is also readily formed by coldworking. All hot- or coldworked parts should be annealed and rapidly cooled in order to restore the best balance of properties. The alloy can be welded by a variety of techniques, including gas tungsten arc (GTAW), gas metal arc (GMAW), and resistance welding.

Heat-Treatment

Wrought 230® alloy is furnished in the solution heat-treated condition, unless otherwise specified. The alloy is solution heat-treated in the range of 2150 to 2275°F (1177 to 1246°C) and rapidly cooled or water-quenched for optimum properties.

Annealing at temperatures lower than the solution heat-treating temperatures will produce some carbide precipitation in 230® alloy, which may marginally affect the alloy’s strength and ductility.

Castings

HAYNES® 230® alloy may be cast using traditional air-melt sand mold or vacuum-melt investment casting foundry practices. Silicon levels at the high end of the specification range are recommended for enhanced fluidity. Castings may be used in either the as-cast or solution-heat-treated condition depending upon property requirements.

Principal Features Continued

Applications

HAYNES® 230® alloy combines properties which make it ideally suited for a wide variety of component applications in the aerospace and power industries. It is used for combustion cans, transition ducts, flame holders, thermocouple sheaths, and other important gas turbine components. In the chemical process industry, 230® alloy is used for catalyst grid supports in ammonia burners, high-strength thermocouple protection tubes, high-temperature heat exchangers, ducts, high-temperature bellows, and various other key process internals.

In the industrial heating industry, applications for 230® alloy include furnace retorts, chains and fixtures, burner flame shrouds, recuperator internals, dampers, nitriding furnace internals, heat-treating baskets, grates, trays, sparger tubes, thermocouple protection tubes, cyclone internals, and many more.

Nominal Composition

Weight %

Nickel:	57 Balance
Chromium:	22
Tungsten:	14
Molybdenum:	2
Iron:	3 max.
Cobalt:	5 max.
Manganese:	0.5
Silicon:	0.4
Niobium:	0.5 max.
Aluminum:	0.3
Titanium:	0.1 max.
Carbon:	0.1
Lanthanum:	0.02
Boron:	0.015 max.

Creep and Rupture Properties

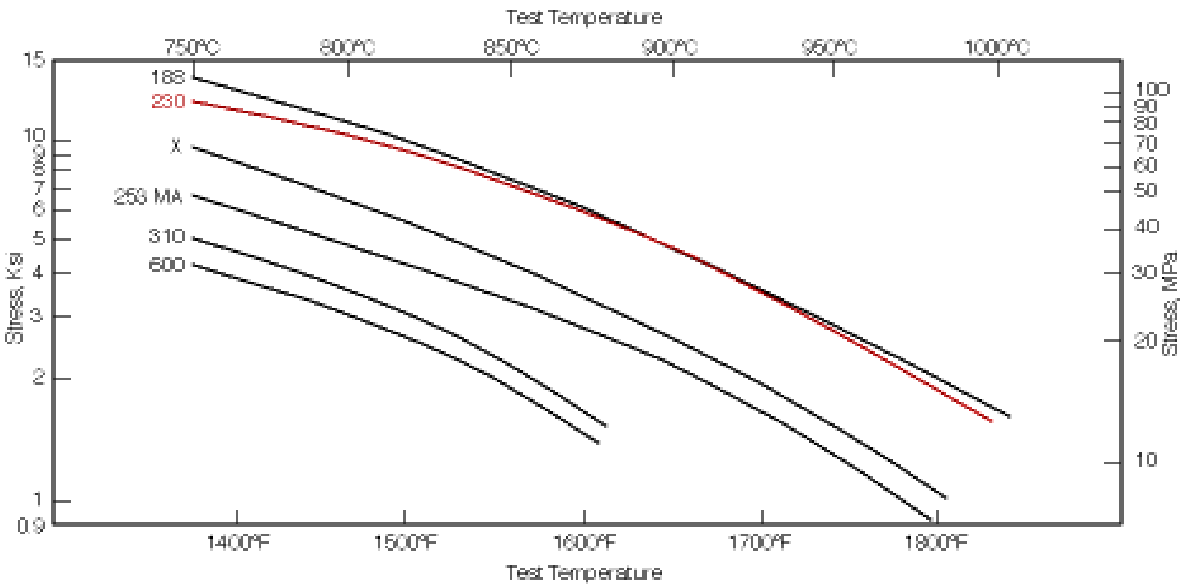
HAYNES® 230® alloy is a solid-solution-strengthened material which combines excellent high-temperature strength with good fabricability at room temperature. It is particularly effective for very long-term applications at temperatures of 1200°F (650°C) or more, and is capable of outlasting stainless steels and nickel alloys by as much as 100 to 1 depending upon the temperature. Alternatively, the higher strength of 230® alloy allows for the use of design section thicknesses as much as 75 percent thinner than lesser alloys with no loss in load-bearing capability.

Stress-Rupture Lives for Various Alloys at Fixed Test Conditions (Bar and Plate)*

Alloy	Hours to Rupture		
	1400°F (760°C)	1600°F (871°C)	1800°F (982°C)
-	15.0 ksi (103 MPa)	4.1 ksi (31 Mpa)	2.0 ksi (14 Mpa)
230®	**8,200**	**65,000**	**5,000**
625	19,000	14,000	2,400
X	900	5,000	2,100
800H	130	1,200	920
INCONEL® 601	50	1,200	1,000
253 MA®	140	900	720
600	15	280	580
316 SS	100	240	130
RA330®	30	230	130
304 SS	10	100	72

*Based upon Larson-Miller extrapolation

Comparison of Stress to Produce 1% Creep in 1000 Hours (Sheet)



Creep and Rupture Properties Continued

230® Sheet, Solution Annealed

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in							
			10 Hours		100 Hours		1,000 Hours		10,000 Hours	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	0.5	-	-	31	214	-	-	-	-
		1	-	-	35	241	24*	165*	-	-
		R	-	-	51	352	36	248	28	193
1300†	704	0.5	29	200	21	145	14.5	100	-	-
		1	33	228	23	159	17	114	-	-
		R	47	324	34	234	26	179	20	134
1400	760	0.5	19.2	132	13.7	94	9.6	66	7.3	50
		1	21	145	15.5	107	11.5	79	8.6	59
		R	32	221	24.5	169	18.2	125	13.2*	91*
1500	816	0.5	14.2	98	10.3	71	7.5	52	5.4*	37*
		1	15	103	11.2	77	8.6	59	6.5*	45*
		R	23*	161*	17.5	121	12.5	86	8.4*	58*
1600	871	0.5	11.3	78	8.1	56	5.7	39	4.0	28
		1	11.7	81	9.0	62	6.2	43	4.3	30
		R	17.0	117	12.5	86	8.2	57	5.6*	39*
1700	927	0.5	7.7	53	5.5	38	3.8	26	2.4*	17*
		1	8.8*	61*	6.2	43	4.2	29	2.7*	19*
		R	12.0*	83*	8.0	55	5.1	35	3.2	22
1800	982	0.5	7.0	48	3.6	25	1.8	12	0.85	5.9
		1	8.0	55	4.1	28	2.0	14	1.0	6.9
		R	10.0	69	5.4	37	2.6	18	1.2*	8.3*
1900	1038	0.5	-	-	1.7	12	0.8	5.5	-	-
		1	-	-	2.0	14	0.9	6.2	-	-
		R	-	-	3.0*	21*	1.5	10	-	-
2000	1093	0.5	-	-	-	-	-	-	-	-
		1	-	-	0.9	6.2	-	-	-	-
		R	-	-	-	-	-	-	-	-

*Significant Extrapolation

Creep and Rupture Properties Continued

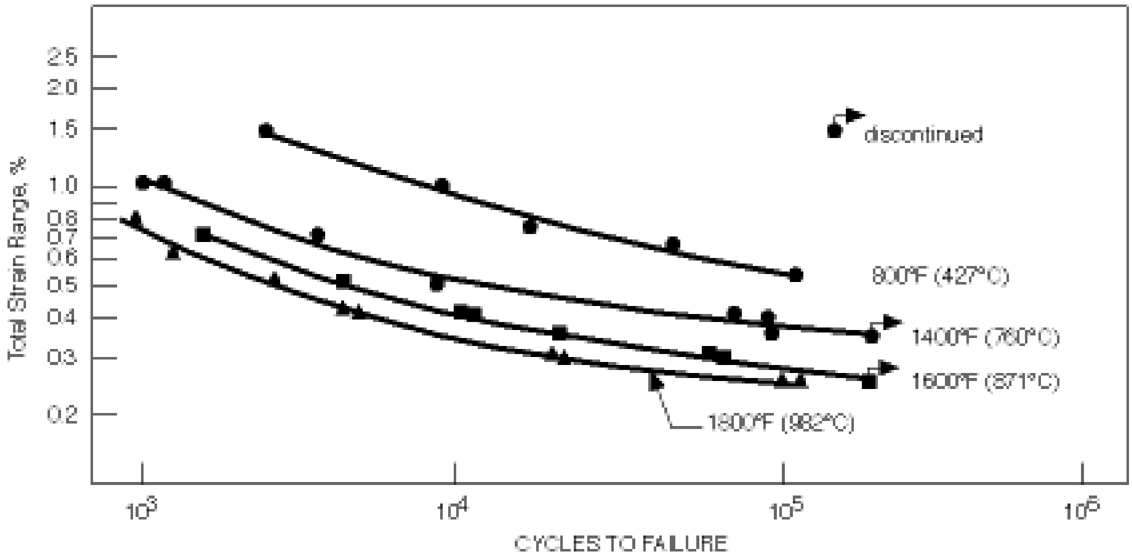
230® Plate, Solution Annealed

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in							
			10 Hours		100 Hours		1,000 Hours		10,000 Hours	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	0.5	-	-	35	241	23	159	-	-
		1	-	-	39	269	26.5	183	17.5	121
		R	75	517	56	386	41	283	29	200
1300	704	0.5	35	241	21.5	148	14.5	100	-	-
		1	39	269	24.5	169	18	124	12.3*	85*
		R	59	407	42	290	30	207	21	145
1400	760	0.5	19	131	13.5	93	10.0	69	-	-
		1	23	159	15.9	110	11.5	79	9.0*	62*
		R	37	255	27	186	20	138	14.2	98
1500	816	0.5	14.0	97	10.4	72	8.2	57	6.1	42
		1	16.5	114	12.5	86	9.5	66	6.9	48
		R	26	179	20	138	14.0	97	9.8	68
1600	871	0.5	10.3	71	7.6	52	5.6	39	4.0	28
		1	11.7	81	9.0	62	6.2	43	4.3	30
		R	20	138	13.7	94	9.5	66	6.2	43
1700	927	0.5	7.8	54	5.7	39	3.9	27	2.5	17
		1	8.8	61	6.8	47	4.5	31	2.7	19
		R	15.0	103	10.0	69	6.0	41	3.6	25
1800	982	0.5	5.8	40	3.5	24	1.8	12	0.90	6.2
		1	6.3	43	4.0	28	2.1	14	1.1	7.6
		R	9.4	65	6.0	41	3.2	22	1.7	12
1900	1038	0.5	4.0	28	2.0	14	0.90	6.2	-	-
		1	4.4	30	2.2	15	1.0	6.9	0.50*	3.4*
		R	7.0	48	3.7	26	1.8	12	1.0	6.9
2000	1093	0.5	1.9	13	0.80	5.5	0.35	2.4	--	--
		1	2.3	16	1.0	6.9	0.47	3.2	0.20*	1.4*
		R	4.2	29	2.1	14	1.0	6.9	0.55	3.8
2100	1149	0.5	0.80	5.5	0.03*	2.1*	-	-	-	-
		1	1.0	6.9	0.43	3.0	-	-	-	-
		R	2.3	16	1.2	8.3	0.60	4.1	-	-

*Significant Extrapolation

Low Cycle Fatigue

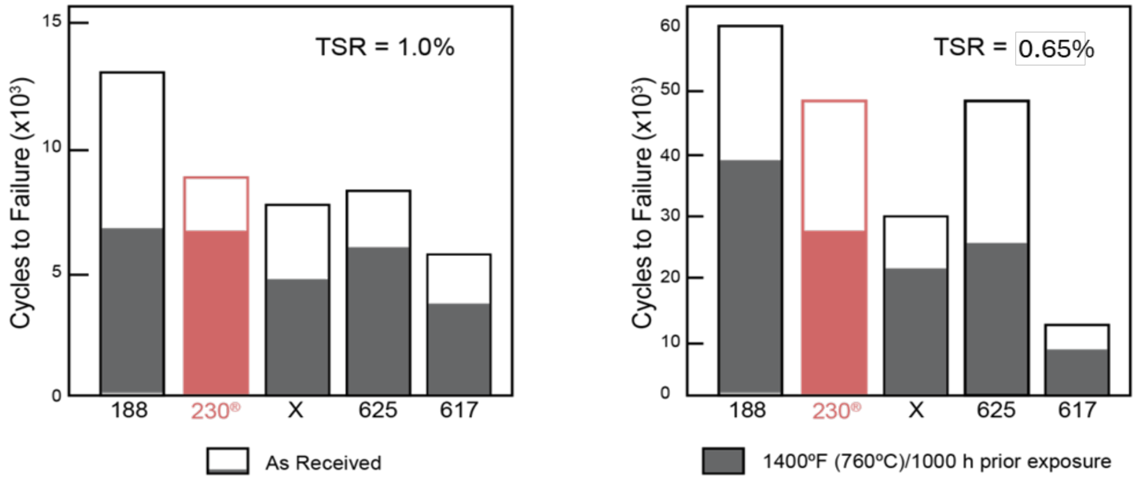
HAYNES® 230® alloy exhibits excellent low cycle fatigue properties at elevated temperature. Results shown below are for strain-controlled tests run in the temperature range from 800 to 1800°F (425 to 980°C). Samples were machined from plate. Tests were run with fully reversed strain (R= -1) at a frequency of 20 cpm (0.33 Hz).



Comparative Low Cycle Fatigue Properties

The graph below compares the low cycle fatigue lives of a number of alloys tested at 800°F (427°C) in both the as-received and 1400°F (760°C)/1000 hour pre-exposed condition. Samples were machined from plate or bar, after exposure for exposed samples. Tests were again 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



Compilation of axial LCF test results (R=-1, f=0.33 Hz)

Temperature		Δεtot/%	Ni, Cycles to Initiation	Nf, Cycles to Failure
°F	°C	-	-	-
800	427	1.50	2230	2398
		1.00	8480	8742
		0.80	14,918	16,575
		0.65	45,127	46,523
		0.55	103,910	115,456

* Indicates a run-out.

Low Cycle Fatigue Continued

Compilation of axial LCF test results (R=-1, f=0.33 Hz)

Temperature		Δεtot/%	Ni, Cycles to Initiation	Nf, Cycles to Failure
°F	°C	-	-	-
1000	538	1.50	1329	1540
		1.25	1974	2368
		1.00	3330	4413
		0.80	7864	8734
		0.70	8423	9876
		0.60	38,696	40,604
		0.56	73,014	74,132
		0.53	--	200,005*
		0.50	--	201,190*
1200	649	1.25	1022	1257
		1.00	1852	2254
		0.80	3431	4248
		0.60	8962	11,058
		0.50	82,275	85,563
		0.45	--	200,002*
		0.40	--	200,005*
1400	760	0.80	1896	2218
		0.40	20,519	21,564
		0.40	43,915	45,279
		0.30	--	203,327*
1400	760	1.00	870	1097
		1.00	827	990
		0.70	3166	3622
		0.50	8153	8490
		0.40	51,285	57,819
		0.40	68,451	75,470
		0.38	95,165	96,844
		0.37	91,879	97,612
		0.35	--	202,920*
		0.30	--	150,000*
1600	871	0.70	1279	1504
		0.50	3939	4299
		0.50	3176	3473
		0.40	9712	10,837
		0.40	9296	10,781
		0.35	19,179	20,964
		0.31	61,898	63,253
		0.30	65,691	66,926
		0.25	--	200,770*
1800	982	0.60	818	1218
		0.50	1506	2582
		0.40	3520	4223
		0.40	3070	4784
		0.30	19,810	21,311
		0.30	13,904	19,200
		0.25	105,140	106,020
		0.25	116,960	119,890

Tensile Properties

Tensile Properties of 230® Sheet

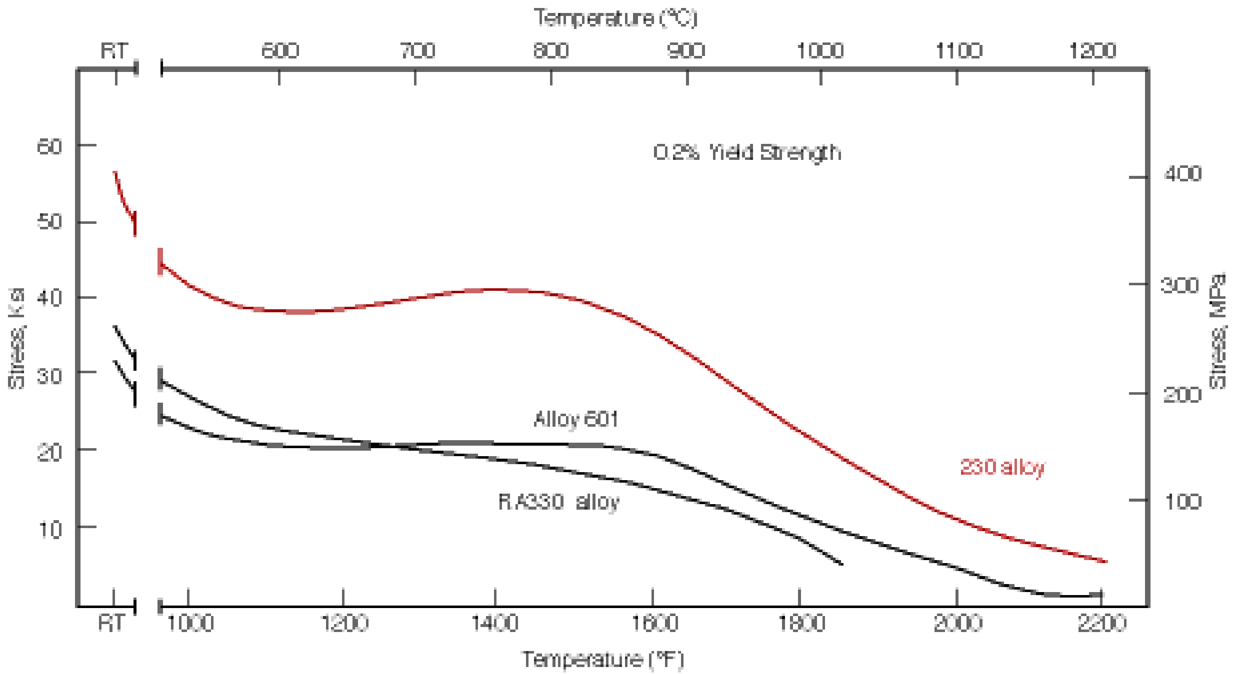
Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
70	21	60.4	417	121.4	837	47.3
1000	538	42.6	294	100.1	690	51.7
1200	649	42.2	291	96.6	666	56.9
1400	760	45.1	311	78.0	538	59.5
1600	871	34.2	236	44.6	308	74.2
1800	982	17.8	123	24.5	169	54.1
2000	1093	10.0	69	13.1	90	37.0

Tensile Properties of 230® Plate

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
70	21	55.5	383	123.6	852	46.0
1000	538	38.1	263	102.5	706	53.2
1200	649	38.7	267	98.2	677	53.0
1400	760	37.7	260	77.2	533	68.0
1600	871	33.9	234	45.1	311	94.0
1800	982	16.8	116	24.3	168	91.2
2000	1093	9.1	63	13.2	91	92.1

RT= Room Temperature

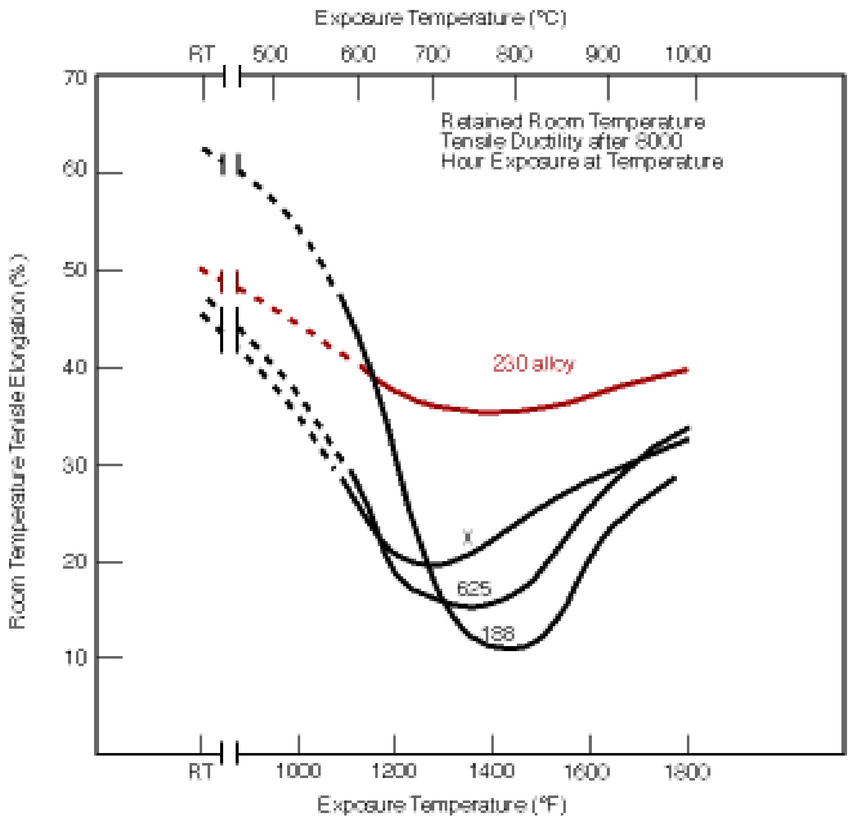
Comparison of Yield Strengths (Plate)



Thermal Stability

HAYNES® 230® alloy exhibits excellent retained ductility after long-term thermal exposure at intermediate temperatures. It does not exhibit sigma phase, mu phase, or other deleterious phase formation even after 16,000 hours of exposure at temperatures from 1200 to 1600°F (649 to 871°C). Principal phases precipitated from solid solution are all carbides.

This contrasts markedly with many other solid-solution-strengthened superalloys such as HAYNES® 188 alloy, HAYNES® 625 alloy, and HASTELLOY® X alloy. These alloys all precipitate deleterious phases, which impair both tensile ductility and impact strength.



Thermal Stability Continued

Room-Temperature Properties after Thermal Exposure

Condition	0.2% Yield Strength	Ultimate Tensile Strength	Elongation	R.A.	Impact Strength
	ksi	ksi	%	%	ft-lb
MA	58.4	123.1	50	47.2	54
+1200/8,000 hr.	57.9	128.0	36.4	39	31.4
+1200/20,000 hr.	57.6	128.4	34.8	37	28.9
+1200/30,000 hr.	59.4	129.9	34	38.3	
+1200/50,000 hr.	61.2	131.7	33.9	36.9	25.8
+1400/8,000 hr	59.2	129.7	32	34.3	18.7
+1400/20,000 hr	55.0	126.9	31.2	31.6	18.8
+1400/30,000 hr	54.3	126.9	31.3	33.9	
+1400/50,000 hr	55.2	127.7	32.2	32.5	20.7
+ 1600/8,000 hr.	54.3	122.7	36.2	34.6	21.6
+ 1600/20,000 hr.	50.1	121.6	34.4	31.1	19.5
+ 1600/30,000 hr.	49.6	120.0	32.1	28.6	
+ 1600/50,000 hr.	116.7	116.7	25.2*	20.2	14.8

*BIGM; AGL Elong, which tends to be lower; Other data are 4D Elong.
R.A.= Reduction of Area

Retained Room Temperature Tensile Ductility after 8000 Hour Exposure at Temperature

Exposure Temperature	Room Temperature Tensile Elongation	Room Temperature Tensile Elongation	Room Temperature Tensile Elongation	Room Temperature Tensile Elongation
	230®	188	625	X
°F	%	%	%	%
1200	**36.4**	29.1	18	19
1400	**32**	10.8	13	19
1600	**36.2**	22.2	26	30

Resistance to Grain Growth

HAYNES® 230® alloy exhibits excellent resistance to grain growth at high temperatures. As a consequence of its very stable primary carbides, 230 alloy can be exposed at temperatures as high as 2200°F (1204°C) for up to 24 hours without exhibiting significant grain growth. Materials such as HAYNES 188 alloy or HASTELLOY® X alloy exhibit greater grain growth under such conditions, as would most iron-, nickel-, or cobalt-base alloys and stainless steels.

Exposure Time	Grain Size for Alloys Exposed at Temperature for Various Times*					
	HAYNES® 230® alloy		HAYNES® 188 alloy		HASTELLOY® X alloy	
h	2150°F (1177°C)	2200°F (1204°C)	"2150°F (1177°C)"	2200°F (1204°C)	2150°F (1177°C)	2200°F (1204°C)
0	**4-4 1/2**	**4-4 1/2**	4-5	4-5	3 1/2	3 1/2
1	**4-5**	**4-4 1/2**	2-5	2-4	3 1/2	0-1
4	**4-4 1/2**	**4-4 1/2**	3 1/2	3	3 1/2	0-1
24	**4**	**4-4 1/2**	0-2	1-3	00-4	0-1 1/2

*Plate Product

Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.324 lb/in^3	RT	8.97 g/cm^3
Melting Temperature	2375-2500°F	-	1301-1371°C	-
Electrical Resistivity	RT	49.2 µohm-in	RT°C	125.0 µohm-m
	200°F	49.5 µohm-in	100°C	125.8 µohm-m
	400°F	49.8 µohm-in	200°C	126.5 µohm-m
	600°F	50.2 µohm-in	300°C	127.3 µohm-m
	800°F	50.7 µohm-in	400°C	128.4 µohm-m
	1000°F	51.5 µohm-in	500°C	130.2 µohm-m
	1200°F	51.6 µohm-in	600°C	131.2 µohm-m
	1400°F	51.1 µohm-in	700°C	130.7 µohm-m
	1600°F	50.3 µohm-in	800°C	129.1 µohm-m
	1800°F	49.3 µohm-in	900°C	127.1 µohm-m
	-	-	1000°C	125.0 µohm-m
Thermal Diffusivity	RT	3.8 x 10^{-3}in^2/sec	RT	24.2 x 10^{-3}cm^2/s
	200°F	4.1 x 10^{-3}in^2/sec	100°C	26.8 x 10^{-3}cm^2/s
	400°F	4.7 x 10^{-3}in^2/sec	200°C	29.9 x 10^{-3}cm^2/s
	600°F	5.2 x 10^{-3}in^2/sec	300°C	32.9 x 10^{-3}cm^2/s
	800°F	5.6 x 10^{-3}in^2/sec	400°C	35.7 x 10^{-3}cm^2/s
	1000°F	6.1 x 10^{-3}in^2/sec	500°C	38.5 x 10^{-3}cm^2/s
	1200°F	6.5 x 10^{-3}in^2/sec	600°C	41.9 x 10^{-3}cm^2/s
	1400°F	6.7 x 10^{-3}in^2/sec	700°C	43.0 x 10^{-3}cm^2/s
	1600°F	6.7 x 10^{-3}in^2/sec	800°C	43.2 x 10^{-3}cm^2/s
	1800°F	7.3 x 10^{-3}in^2/sec	900°C	44.4 x 10^{-3}cm^2/s
	-	-	1000°C	48.2 x 10^{-3}cm^2/s
Thermal Conductivity	RT	62 Btu-in/ft^2-hr-°F	RT	8.9 W/m-°C
	200°F	71 Btu-in/ft^2-hr-°F	100°C	10.4 W/m-°C
	400°F	87 Btu-in/ft^2-hr-°F	200°C	12.4 W/m-°C
	600°F	102 Btu-in/ft^2-hr-°F	300°C	14.4 W/m-°C
	800°F	118 Btu-in/ft^2-hr-°F	400°C	16.4 W/m-°C
	1000°F	133 Btu-in/ft^2-hr-°F	500°C	18.4 W/m-°C
	1200°F	148 Btu-in/ft^2-hr-°F	600°C	20.4 W/m-°C
	1400°F	164 Btu-in/ft^2-hr-°F	700°C	22.4 W/m-°C
	1600°F	179 Btu-in/ft^2-hr-°F	800°C	24.4 W/m-°C
	1800°F	195 Btu-in/ft^2-hr-°F	900°C	26.4 W/m-°C
	-	-	1000°C	28.4 W/m-°C

RT= Room Temperature

Physical Properties Continued

Physical Property	British Units		Metric Units	
Specific Heat	RT	0.095 Btu/lb-°F	RT	397 J/kg·°C
	200°F	0.099 Btu/lb-°F	100°C	419 J/kg·°C
	400°F	0.104 Btu/lb-°F	200°C	435 J/kg·°C
	600°F	0.108 Btu/lb-°F	300°C	448 J/kg·°C
	800°F	0.112 Btu/lb-°F	400°C	465 J/kg·°C
	1000°F	0.112 Btu/lb-°F	500°C	473 J/kg·°C
	1200°F	0.134 Btu/lb-°F	600°C	486 J/kg·°C
	1400°F	0.140 Btu/lb-°F	700°C	574 J/kg·°C
	1600°F	0.145 Btu/lb-°F	800°C	5595 J/kg·°C
	1800°F	0.147 Btu/lb-°F	900°C	609 J/kg·°C
	-	-	1000°C	617 J/kg·°C
Mean Coefficient of Thermal Expansion	70-200°F	6.5 µin/in -°F	25-100°C	11.8 x 10-6m/m·°C
	70-400°F	6.9 µin/in -°F	25-200°C	12.4 x 10-6m/m·°C
	70-600°F	7.2 µin/in -°F	25-300°C	12.8 x 10-6m/m·°C
	70-800°F	7.4 µin/in -°F	25-400°C	13.2 x 10-6m/m·°C
	70-1000°F	7.6 µin/in -°F	25-500°C	13.6 x 10-6m/m·°C
	70-1200°F	8.0 µin/in -°F	25-600°C	14.1 x 10-6m/m·°C
	70-1400°F	8.3 µin/in -°F	25-700°C	14.7 x 10-6m/m·°C
	70-1600°F	8.6 µin/in -°F	25-800°C	15.2 x 10-6m/m·°C
	70-1800°F	8.9 µin/in -°F	25-900°C	15.7 x 10-6m/m·°C
	-	-	25-1000°C	16.1 x 10-6m/m·°C
Dynamic Modulus of Elasticity	RT	30.3 x 10^6 psi	RT	209 GPa
	200°F	30.1 x 10^6 psi	100°C	207 GPa
	400°F	29.0 x 10^6 psi	200°C	200 GPa
	600°F	27.8 x 10^6 psi	300°C	193 GPa
	800°F	26.8 x 10^6 psi	400°C	186 GPa
	1000°F	25.9 x 10^6 psi	500°C	181 GPa
	1200°F	24.9 x 10^6 psi	600°C	175 GPa
	1400°F	23.6 x 10^6 psi	700°C	168 GPa
	1600°F	22.2 x 10^6 psi	800°C	159 Gpa
	1800°F	20.7 x 10^6 psi	900°C	150 Gpa
	2000ºF	19.1 x 10^6 psi	1000°C	141 Gpa

RT= Room Temperature

Physical Properties Continued

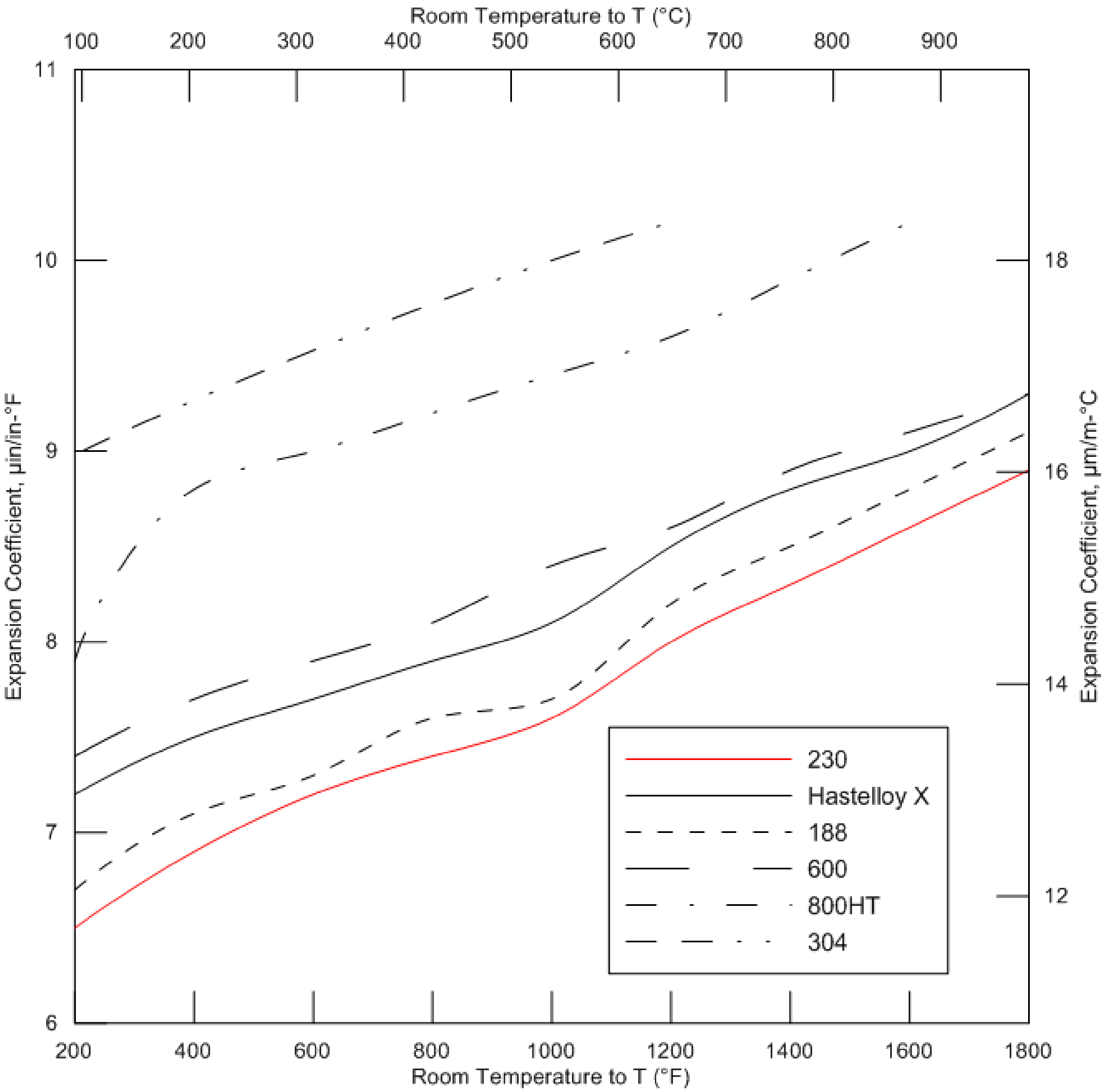
Physical Property	British Units		Metric units	
Dynamic Shear Modulus	RT	11.5 x 10^6 psi	RT	79 Gpa
	200°F	11.4 x 10^6 psi	100°C	79 Gpa
	400°F	11.0 x 10^6 psi	200°C	76 Gpa
	600°F	10.5 x 10^6 psi	300°C	73 Gpa
	800°F	10.1 x 10^6 psi	400°C	70 Gpa
	1000°F	9.7 x 10^6 psi	500°C	67 Gpa
	1200°F	9.3 x 10^6 psi	600°C	64 Gpa
	1400°F	8.8 x 10^6 psi	700°C	61 Gpa
	1600°F	8.2 x 10^6 psi	800°C	57 Gpa
	1800°F	7.6 x 10^6 psi	900°C	52 Gpa
	2000°F	7.0 x 10^6 psi	1000°C	48 Gpa
Poisson's Ratio	RT	0.31	RT	0.31
	200°F	0.31	100°C	0.31
	400°F	0.32	200°C	0.32
	600°F	0.32	300°C	0.32
	800°F	0.33	400°C	0.33
	1000°F	0.33	500°C	0.33
	1200°F	0.34	600°C	0.34
	1400°F	0.34	700°C	0.34
	1600°F	0.35	800°C	0.34
	1800°F	0.36	900°C	0.35

RT= Room Temperature

Physical Properties Continued

Thermal Expansion Characteristics

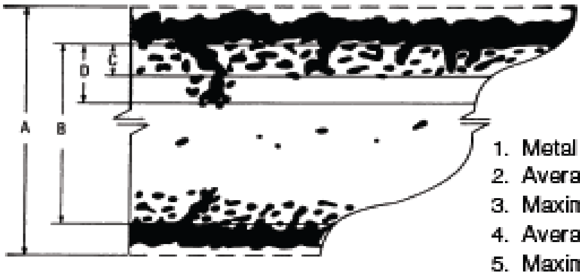
HAYNES® 230® alloy has relatively low thermal expansion characteristics compared to most high-strength superalloys, iron-nickel-chromium alloys, and austenitic stainless steels. This means lower thermal stresses in service for complex component fabrications, as well as tighter control over critical part dimensions and clearances.



Oxidation Resistance

HAYNES® 230® alloy exhibits excellent resistance to both air and combustion gas oxidizing environments, and can be used for long-term continuous exposure at temperatures up to 2100°F (1150°C). For exposures of short duration, 230 alloy can be used at higher temperatures.

Schematic Representation of Metallographic Technique used for Evaluating Oxidation 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

Comparative Dynamic Oxidation

Alloy	1600°F (870°C), 2000 h, 30-min cycles				1800°F (980°C), 1000 h, 30-min cycles				2000°F (1090°C), 500 h, 30-min cycles				2100°F (1150°C), 200 h, 30-min cycles			
	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
188	1.1	28	2.9	74	1.1	28	3.2	81	10.9	277	13.1	333	8	203	9.7	246
230®	**0.9**	**23**	**3.9**	**99**	**2.8**	**71**	**5.6**	**142**	**7.1**	**180**	**9.9**	**251**	**6.4**	**163**	**13.1**	**333**
617	2	51	7.8	198	2.4	61	5.7	145	13.3	338	20.9	531	13.8	351	15.3	389
625	1.2	30	2.2	56	3.7	94	6	152	-	-	Consumed		-	-	-	-
556®	1.5	38	3.9	99	4.1	104	6.7	170	9.9	251	12.1	307	11.5	292	14	356
X	1.7	43	5.3	135	4.3	109	7.3	185	11.6	295	14	356	13.9	353	15.9	404
HR-120®	-	-	-	-	6.3	160	8.3	211	-	-	-	-	-	-	-	-
RA330	2.5	64	5	127	8.7	221	10.5	267	15.4	391	17.9	455	11.5	292	13	330
HR-160®	-	-	-	-	5.4	137	11.9	302	12.5		18.1	460	8.7	221	15.5	394
310SS	6	152	7.9	201	16	406	18.3	465	-	-	-	-	-	-	Consumed	
800H	3.9	99	9.4	239	22.9	582	Through Thick-ness		-	-	Consumed after 300 h		-	-	Consumed	

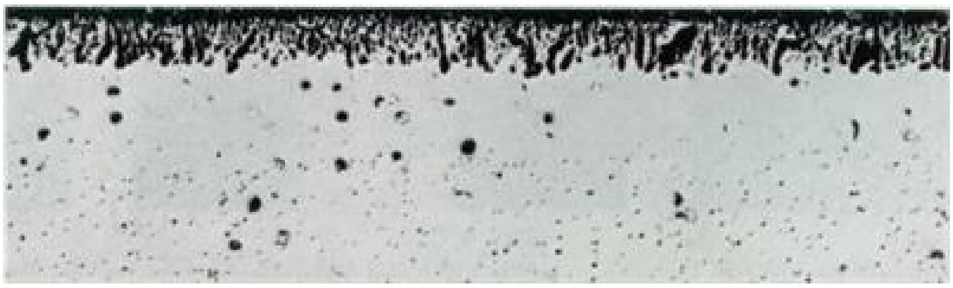
Burner rig oxidation tests were conducted by exposing samples of 3/8" x 2.5" x thickness (9mm x 64 mm x thickness), in a rotating holder to the products of combustion of 2 parts No. 1 and 1 part No. 2 fuel burned at a ratio of air to fuel of about 50:1. Gas velocity was about 0.3 mach. Samples were automatically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

Oxidation Resistance Continued

Comparative Oxidation in Flowing Air 2100°F (1150°C) for 1008 Hours

Microstructures shown are for coupons exposed for 1008 hours at 2100°F (1150°C) in air flowing 7.0 feet/minute (2.1 m/minute) past the samples. Samples were descaled by cathodically charging the coupons while they were immersed in a molten salt solution. The black area shown at the top of each picture represents actual metal loss due to oxidation. The data clearly show HAYNES 230 alloy to be superior to both INCONEL alloy 601 and alloy 800H, as well as the other heat-resistant materials listed in the table above.

230® alloy
Average Metal Affected
= 3.4 mils (86 µm)



INCONEL alloy 601
Average Metal Affected
= 5.3 mils (135 µm)

Alloy 800H
Average Metal Affected
= 8.9 mils (226 µm)

Oxidation Resistance Continued

Water Vapor Testing

Alloy	1008 hours @ 1600F Cycled 1x/week in air+10%H_2O				1008 hours @ 1600F Cycled 1x/week in air+20%H_2O				6 months @ 1400F Cycled 1x/week in air+10%H_2O			
	Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected	
	mils per side	mm per side	mils per side	mm per side	mils per side	mm per side	mils per side	mm per side	mils per side	mm per side	mils per side	mm per side
230®	**0.07**	**0.002**	**0.53**	**0.013**	**0.03**	**0.001**	**0.21**	**0.005**	**0.05**	**0.001**	**0.35**	**0.009**
625	0.11	0.003	0.5	0.013	0.04	0.001	0.27	0.007	-	-	-	-
X	0.03	0.001	0.5	0.013	0.04	0.001	0.3	0.008	-	-	-	-
253MA	0.66	0.017	1.59	0.04	0.08	0.002	0.68	0.017	-	-	-	-
800HT	-	-	-	-	-	-	-	-	0.12	0.003	0.82	0.021
347SS	0.86	0.022	1.48	0.038	0.18	0.005	0.18	0.005	0.46	0.012	1.26	0.032

Amount of metal affected for high-temperature sheet (0.060 - 0.125”) alloys exposed for 360 days (8,640 h) in flowing air.

Alloy	1600°F				1800°F				2000°F				2100°F			
	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
625	0.3	8	1.4	36	-	-	-	-	-	-	-	-	-	-	-	-
230®	**0.2**	**5**	**1.4**	**36**	**0.1**	**3**	**2.5**	**64**	**3.4**	**86**	**11**	**279**	**28.5**	**724**	**34.4**	**874**
617	0.3	8	1.6	41	-	-	-	-	-	-	-	-	-	-	-	-
HR-120®	0.3	8	1.6	41	0.5	13	3.3	84	18.1	460	23.2	589	33.6	853	44	1118
25	0.3	8	1.7	43	-	-	-	-	-	-	-	-	-	-	-	-
188	0.2	5	1.8	46	-	-	-	-	-	-	-	-	-	-	-	-
556®	0.3	8	1.9	48	0.5	13	6.2	157	15	381	24.1	612	-	-	-	-
X	0.3	8	2.2	56	0.2	5	2.8	71	17.1	434	26.2	665	51.5	1308	55.4	1407
800HT	0.4	10	2.9	74	-	-	-	-	-	-	-	-	-	-	-	-
HR-160®	-	-	-	-	1.7	43	13.7	348	7.2	183	30.8	782	12	305	45.6	1158

*Metal loss was calculated from final and initial metal thicknesses; i.e. ML = (OMT – FMT) /2

Static Oxidation Comparison

Alloy	Comparative Oxidation Resistance in Flowing Air, 1008 Hours*															
	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
230®	**0.2**	**5**	**1.5**	**38**	**0.5**	**13**	**3.3**	**84**	**1.2**	**30**	**4.4**	**112**	**4.7**	**119**	**8.3**	**211**
188	0.1	3	1.1	28	0.5	13	3.7	94	8.6	218	10.7	272	5.2	132	48.2	1224
601	0.4	10	1.7	43	1.3	33	3.8	97	2.8	71	6.5	165	4.4	112	7.5	191
617	0.3	8	2	51	0.6	15	3.8	97	1	25	5.2	132	10.7	272	12.6	320
X	0.2	5	1.5	38	1.3	33	4.4	112	3.6	91	6.1	115	-	-	-	-
800HT	0.5	13	4.1	104	7.6	193	11.6	295	12.4	315	15	381	-	-	-	-
446 SS	-	-	-	-	13	330	14.4	366	-	-	>21.5	>546	-	-	-	-
316 SS	12.3	312	14.2	361	-	-	>17.5	>445	-	-	>17.5	>445	-	-	-	-

*Metal Loss + Average Internal Penetration

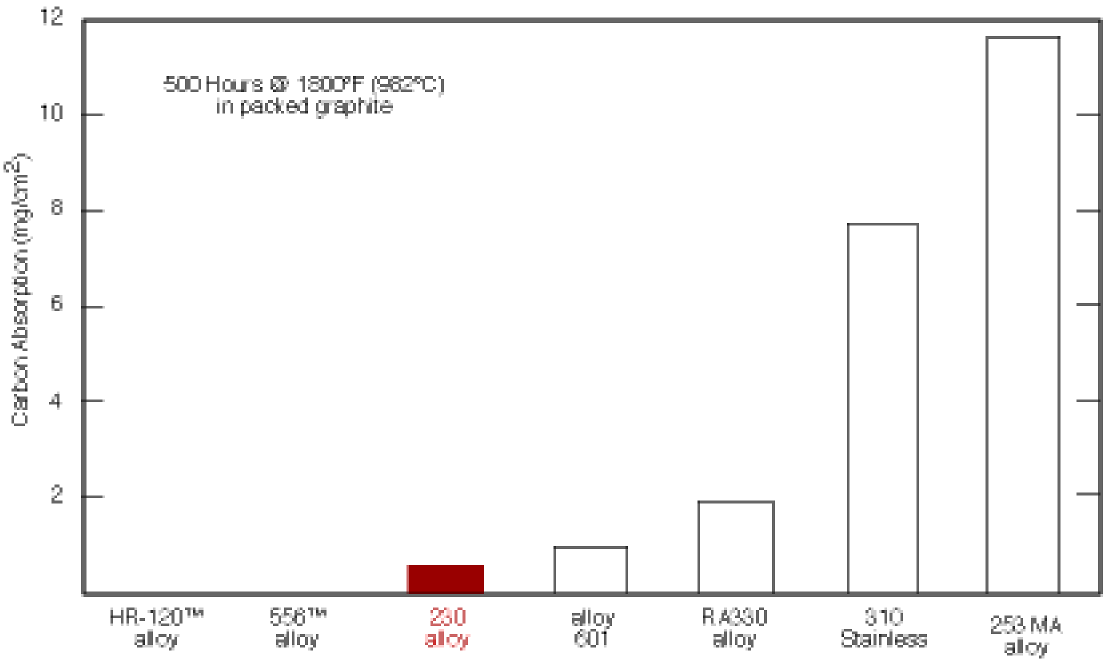
Nitriding Resistance

HAYNES® 230® alloy is one of the most nitriding resistant materials commercially available. Tests were performed in flowing ammonia at 1200°F (650°C) and 1800°F (980°C) for 168 hours. Nitrogen absorption was determined by chemical analysis of samples before and after exposure and knowledge of the exposed specimen area.

Alloy	Nitrogen Absorption (mg/cm^2)		
	1200°F (649°C)	**1800°F (982°C)**	**2000°F (1093°C)**
230®	**0.7**	**1.4**	**1.5**
600	0.8	0.9	0.3
625	0.8	2.5	3.3
X	1.7	3.2	3.8
RA330®	-	3.9	3.1
800H	4.3	4.0	5.5
316 SS	6.9	6.0	3.3
310 SS	7.4	7.7	9.5
304 SS	9.8	7.3	3.5

Carburization Resistance

HAYNES® 230® alloy exhibits good resistance to carburization when compared with many other industrial alloys. Test results were generated for 500 hours exposure in packed graphite at 1800°F (980°C). Carbon absorption was determined by chemical analysis of samples before and after exposure and knowledge of the exposed specimen area.



Hydrogen Embrittlement

Notched tensile tests performed in hydrogen and air reveal that 230® alloy is resistant to hydrogen embrittlement. Tests were performed in MIL-P-27201B grade hydrogen, with a crosshead speed of 0.005 in/min (0.13 mm/min). Specimens were notched with a KT value of 8.0.

Test Temperature		Hydrogen Pressure		Ratio of Notched Tensile Strength, Hydrogen/Air
°F	°C	psig	MPa	-
70	21	3000	21	0.92
70	21	5000	34	1.07

Aqueous Corrosion Resistance

Coupons were exposed for four 24-hour periods in various acids at the stated temperatures, and general corrosion rates were calculated from weight change measurements.

Alloy	Corrosion Rate (mils per year)		
-	10% HNO_3 Boiling	10% H_2SO_4 150°F (66°C)	10% HCl 150°F (66°C)
230®	**0.3**	**0.6**	**112**
625	0.7	0.4	65
600	0.8	41.8	366
316 SS	1	17.8	3408
X	-	<0.1	99

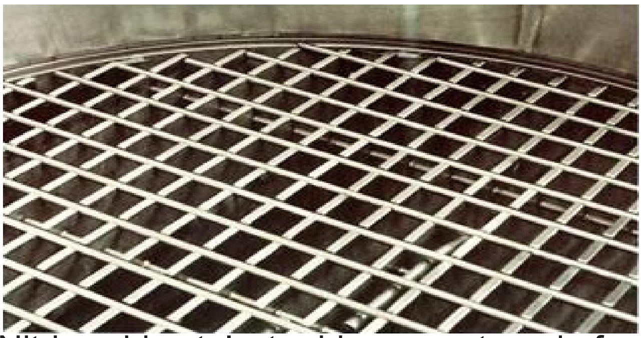
Hardness and Grain Size

Solution Annealed Room Temperature Hardness

Form	Hardness, HRBW	Typical ASTM Grain Size
Sheet	92	4 - 6.5
Plate	92	3 - 5
Bar	90	3 - 5

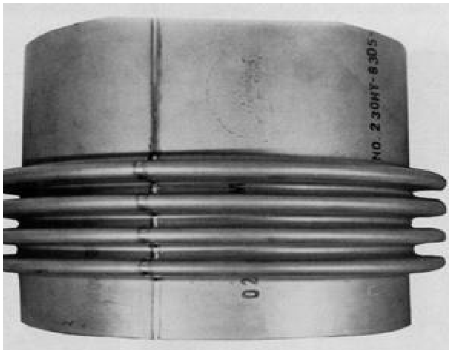
HRBW = Hardness Rockwell “B”, Tungsten Indentor.

Applications



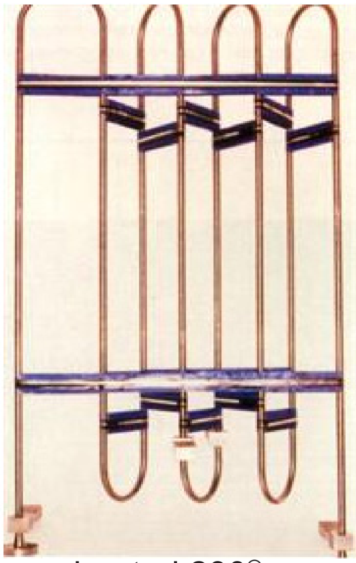
Nitric acid catalyst grids support made from HAYNES® 230® alloy plate and bar. Excellent creep strength at 1700°F (927°C) makes the alloy highly suitable for this application.

Prototype 230® combustor for Dresser-Rand DR-990 industrial turbine.

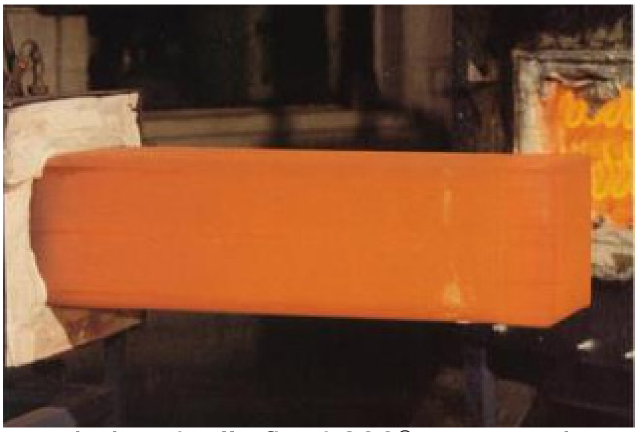


Prototype 230® high-temperature expansion bellows made of 0.020-inch (0.5mm) thick sheet in a catalytic cracker configuration.

Textron Lycoming gas turbine engine combustor made of HAYNES® 230® alloy.

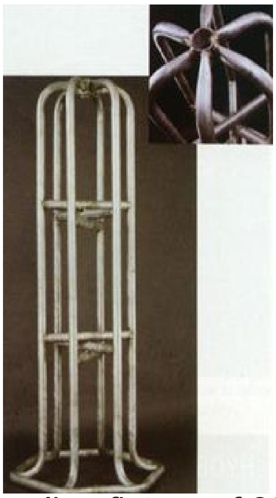


Resistance-heated 230® superheater tubes at the Penn State Applied Research Laboratory. Used to produce about 1625°F (885°C) high-pressure steam.



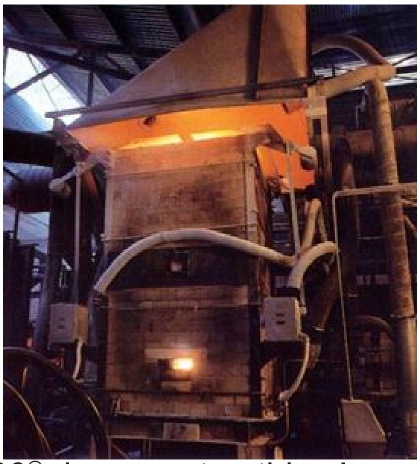
This horizontal electrically fired 230® retort replaced an alloy 600 retort which lasted only an average of eight months in 1400 to 2200°F (760 to 1205°C) service in hydrogen atmosphere. The 230 retort was still in excellent condition after 24 months service, as shown.

Applications Continued

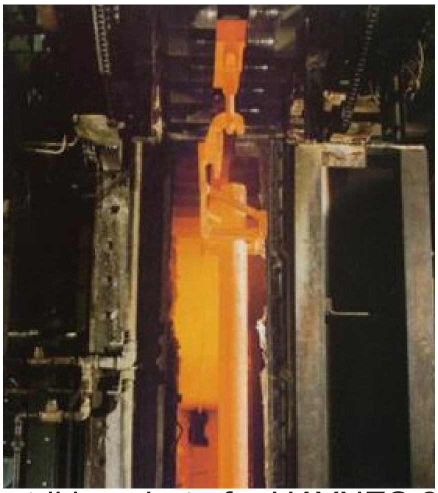


Wire annealing fixture of 230 alloy reduces thermal mass and cycle times after replacing massive carbon-steel "stub" used previously.

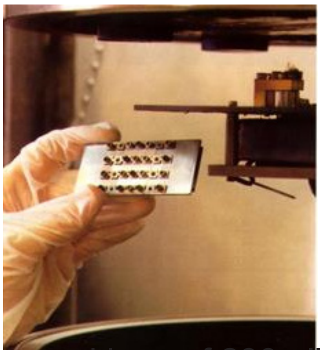
Fabricated heat-treating basket for vacuum furnace application to 2300°F (1260°C). Made from 1/2-inch (12.7 mm) diameter 230® bar.



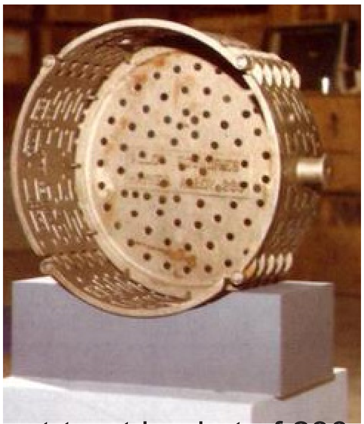
HAYNES® 230® damper atop this glass melting furnace withstands 2300°F (1260°C) for short times and 2000°F (1095°C) for sustained periods.



This striking shot of a HAYNES 230 heat-treat fixture was taken at a leading off-road automotive equipment plant. This conveyor fixture operates at 1550°F (845°C) with a subsequent water quench followed by a four hour cycle at 1050°F (565°C).



Substrate holder and box of 230 alloy resist temperatures of 1650°F (900°C) during the production of semiconductors.



Cast heat-treat basket of 230 alloy in use at Alloy Foundries, Division of the Eastern Company, Naugatuck, Connecticut.

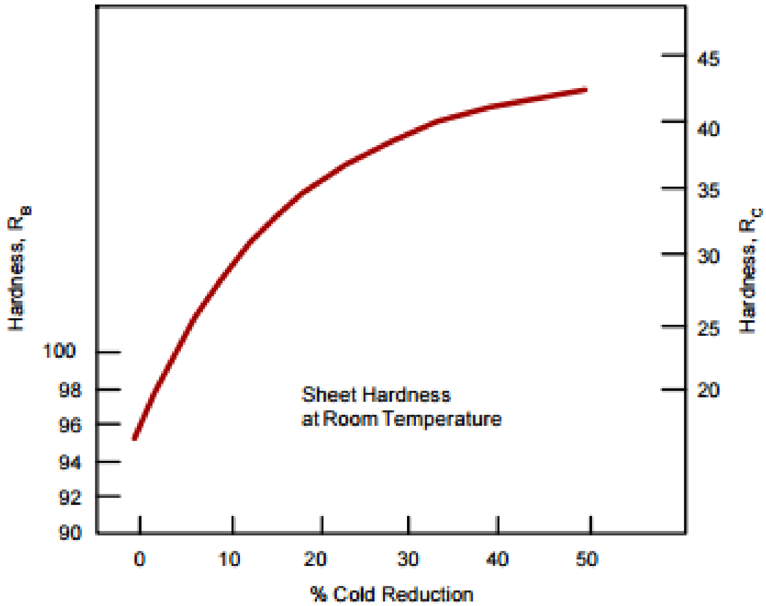
230 retorts operate at 2100°F (1150°C) with a hydrogen atmosphere (inside) and combustion products outside.

Fabrication

Heat Treatment

HAYNES® 230® alloy is normally final solution heat-treated at 2250°F (1230°C) for a time commensurate with section thickness. Solution heat-treating can be performed at temperatures as low as about 2125°F (1165°C), but resulting material properties will be altered accordingly. Annealing during fabrication can be performed at even lower temperatures, but a final, subsequent solution heat treatment is needed to produce optimum properties and structure. Please refer to following sections and publication click here for additional information.

Typical Hardness Properties



Effect of Cold Reduction Upon Room-Temperature Tensile Properties*

<table>
<tr><th>Cold Reduction</th><th>Subsequent Anneal Temperature</th><th colspan="2">0.2% Yield Strength</th><th colspan="2">Ultimate Tensile Strength</th><th>Elongation</th></tr>
<tr><th>%</th><th></th><th>ksi</th><th>MPa</th><th>ksi</th><th>MPa</th><th>%</th></tr>
<tr><td>0</td><td rowspan="6">None</td><td>61.8</td><td>425</td><td>128.2</td><td>885</td><td>46.6</td></tr>
<tr><td>10</td><td>104</td><td>715</td><td>144.5</td><td>995</td><td>31.8</td></tr>
<tr><td>20</td><td>133.4</td><td>920</td><td>163.9</td><td>1130</td><td>16.8</td></tr>
<tr><td>30</td><td>160.1</td><td>1105</td><td>187.5</td><td>1295</td><td>9.7</td></tr>
<tr><td>40</td><td>172.4</td><td>1190</td><td>201.5</td><td>1390</td><td>7.5</td></tr>
<tr><td>50</td><td>184.6</td><td>1275</td><td>214.6</td><td>1480</td><td>6</td></tr>
<tr><td>10</td><td rowspan="5">1950°F (1066°C)</td><td>91.9</td><td>635</td><td>143.5</td><td>990</td><td>32.9</td></tr>
<tr><td>20</td><td>80.8</td><td>555</td><td>141.9</td><td>980</td><td>35.6</td></tr>
<tr><td>30</td><td>75.9</td><td>525</td><td>142.1</td><td>980</td><td>35.7</td></tr>
<tr><td>40</td><td>81.2</td><td>560</td><td>145.5</td><td>1005</td><td>32.3</td></tr>
<tr><td>50</td><td>86.1</td><td>595</td><td>147.7</td><td>1020</td><td>34.6</td></tr>
</table>

*Based upon rolling reductions taken upon 0.120-inch (3.0 mm) thick sheet.
Duplicate tests.

Fabrication Continued

Cold Reduction	Subsequent Anneal Temperature	0.2% Yield Strength		Ultimate Tensile Strength		Elongation
10	2050°F (1121°C)	80.8	555	139	960	36.5
20		65.4	450	135.7	935	39.2
30		72	495	140	965	37.6
40		76.1	525	142.3	980	35.5
50		80.8	555	143.9	990	36.3
10	2150°F (1177°C)	55.5	385	129.5	895	43.7
20		64.4	445	134.3	925	40.1
30		70.2	485	138.1	950	38.5
40		73.4	505	139.2	960	38.1
50		71.9	495	137.7	950	39.1

*Based upon rolling reductions taken upon 0.120-inch (3.0 mm) thick sheet.
Duplicate tests.

Microstructure

(ASTM 5 grain size) Annealed at 2250°F (1230°C)

Etchant 95ml
HCl plus 5 gm
oxalic acid, 4 volts

Welding

HAYNES® 230® alloy is readily welded by Gas Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW), Shielded Metal Arc Welding (SMAW), and resistance welding techniques. Its welding characteristics are similar to those for HASTELLOY® X alloy. Submerged Arc Welding (SAW) 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 welding surface and adjacent regions should be thoroughly cleaned with an appropriate solvent prior to any welding operation. All greases, oils, cutting oils, crayon marks, machining solutions, corrosion products, paint, scale, dye penetrant solutions, and other foreign matter should be completely removed. It is preferable, but not necessary, that the alloy be in the solution- annealed condition when welded.

Filler Metal Selection

HAYNES® 230-W® filler wire (AWS A5.14, ERNiCrWMo-1) is recommended for joining 230® alloy by Gas Tungsten Arc or Gas Metal Arc welding. Coated electrodes of 230-W® alloy are also available for Shielded Metal Arc welding in non-ASME code construction. For dissimilar metal joining of 230® alloy to nickel-, cobalt-, or iron- base materials, 230-W® filler wire, HAYNES® 556® alloy (AWS A5.9 ER3556, AMS 5831), HASTELLOY® S alloy (AMS 5838) or HASTELLOY® W alloy (AMS 5786, 5787) welding products may all be considered, depending upon the particular case. Please click here or the Haynes Welding SmartGuide for more information.

Preheating, Interpass Temperatures, and Postweld Heat Treatment

Preheat is not required. Preheat is generally specified as room temperature (typical shop conditions). Interpass temperature should be maintained below 200°F (93°C). Auxiliary cooling methods may be used between weld passes, as needed, providing that such methods do not introduce contaminants. Postweld heat treatment is not generally required for 230® alloy.

Nominal Welding Parameters

Details for GTAW, GMAW and SMAW welding are given here. Nominal welding parameters are provided as a guide for performing typical operations and are based upon welding conditions used in our laboratories.

Room Temperature Transverse Weld Tensile Results – GTAW of 0.205-in / 5.2 mm Plate

0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Fracture Location
ksi	MPa	ksi	MPa	%	
60.2	415	117.7	812	29.6	Weld Metal
58.4	403	113.4	782	28.2	Weld Metal

Welding Continued

Transverse Weld Tensile Results – GTAW of 0.5-in / 12.7 mm Plate

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Fracture Location
°F	°C	ksi	MPa	ksi	MPa	%	
Room Temperature		65.5	452	126.8	874	37.3	Weld Metal
		63.8	440	120	827	27	Weld Metal
1600	871	38.4	265	60.6	418	44.9	Base Metal
		34.8	240	61.8	426	28.9	Weld Metal

Room Temperature Transverse Weld Tensile Results – GMAW of 2.0-in / 50.8 mm Plate

Ultimate Tensile Strength		Fracture Location
ksi	MPa	
116	800	Weld Metal
117	807	Weld Metal
115	793	Weld Metal
116	800	Weld Metal

Room Temperature Transverse Weld Tensile Results – GTAW of 3.0-in / 76.2 mm Plate

Sample Location	0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area	Fracture Location
	ksi	MPa	ksi	MPa	%	%	
Weld Face	74.1	511	109.5	755	27.2	30.9	Weld Metal
	74.6	514	110.7	763	34.8	44.4	Weld Metal
Weld Center	76.5	527	113.3	781	33.1	37.6	Weld Metal
	76.8	530	111.2	767	26.7	32.9	Weld Metal
Weld Root	74.8	516	109.9	758	19.6	24.1	Weld Metal
	74	510	115	793	31	41.3	Weld Metal

HAYNES® 230-W® All-Weld-Metal Tensile Test Results

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	75.7	520	112.6	775	27.3
1800	980	21.2	145	22.7	155	24.6

Specifications and Codes

Specifications

HAYNES® 230® alloy (N06230) HAYNES® 230-W® alloy (N06231)	
Sheet, Plate & Strip	AMS 5878 SB 435/B 435 P= 43
Billet, Rod & Bar	AMS 5891 SB 572/B 572 B 472 P= 43
Coated Electrodes	SFA 5.11 (ENiCrWMo-1) A 5.11 (ENiCrWMo-1) F= 43
Bare Welding Rods & Wire	SFA 5.14 (ERNiCrWMo-1) A 5.14 (ERNiCrWMo-1) AMS 5839 F= 43
Seamless Pipe & Tube	SB 622/B 622 P= 43
Welded Pipe & Tube	SB 619/B 619 SB 626/B 626 P= 43
Fittings	SB 366/B 366 P= 43
Forgings	AMS 5891 SB 564/B 564 P= 43
DIN	17744 No. 2.4733 NiCr22W14Mo
Others	-

Codes

HAYNES® 230® alloy (UNS N06230) HAYNES® 230-W® alloy (UNS N06231)			
ASME	Section I	1650°F (899°C)[1, 4]	
	Section III	Class 1	-
		Class 2	-
		Class 3	-
	Section IV	HF-300.2	500°F (132°C)[1]
	Section VIII	Div. 1	1800°F (982°C)[1, 5, 6]
		Div. 2	-
	Section XII	650°F (343°C)[1]	
	B16.5	1500°F (816°C)[2]	
	B16.34	1500°F (816°C)[3. 7]	
	B31.1	-	
	B31.3	1650°F (900°C)[1]	
MMPDS	6.3.9		

1Plate, Sheet, Bar, Forgings, fittings, welded pipe/tube, seamless pipe/tube

2Plate, Forgings

3Plate, Bar, Forgings, seamless pipe/tube

4This is the maximum design temperature for water service construction. Several ASME Code Cases govern additional usage:

a) Per Section I Code Case 2665, 1300°F (704°C) is the maximum design temperature for molten nitrate salt wetted construction.

b) Per Section I Code Case 2756, autogenous welds can be used in the design range of 1000°F and 1250°F (538-677°C).

c) Weld strength reduction factors are governed by Section I PG-26 and Code Case 2805.

5Section VIII Division 1 Code Case 2671 contains an external pressure chart for 1800°F (982°C).

6For any bolts created from this material, 1650°F is the maximum design temperature. See Section VIII Division 1 Code Case 2775.

7B16 Case 5 allows for higher pressure-temperature ratings for valves made of this material.

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