HAYNES® 244® alloy

HAYNES® 244® alloy is a age-hardenable, nickel-molybdenum-chromium-tungsten alloy with an extended operating temperature range to 1400°F (760°C). This alloy offers improved yield strength and creep rupture strength, versus HAYNES® 242® alloy, as well as a lower thermal expansion. Additionally, the alloy has excellent low-cycle fatigue and good oxidation resistance. The higher strength and lower thermal expansion provides better dimensional control, sealing, and containment characteristics for aero engine designers.

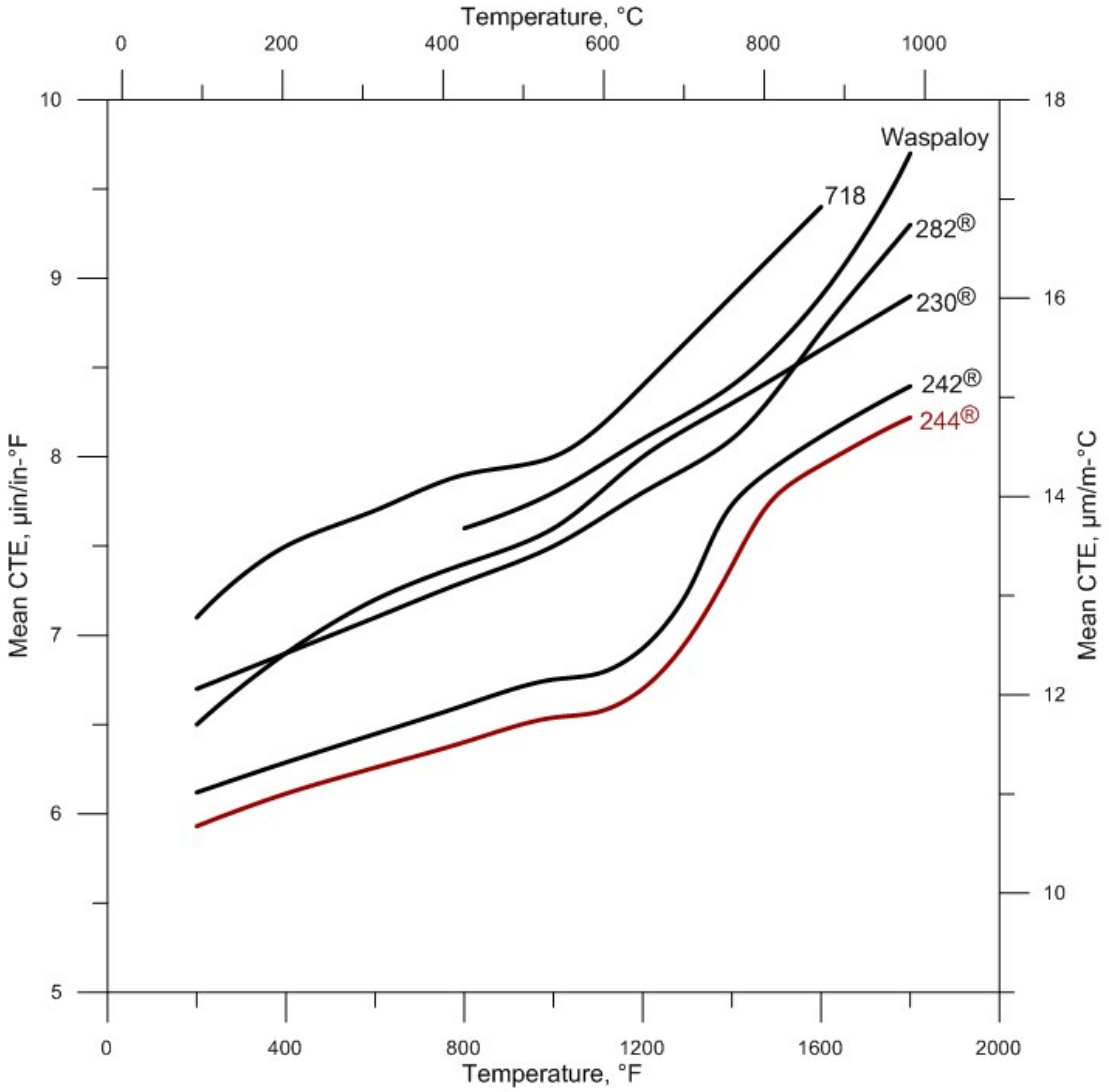
Principal Features

HAYNES® 244® alloy is a new Ni-Mo-Cr-W alloy developed for static parts in advanced gas turbine engines which require low thermal expansion at temperatures up to 1400°F (760°C). It offers a higher maximum use temperature than other low thermal expansion alloys currently available, including a 100-200°F (55-110°C) improvement over HAYNES® 242® alloy. The alloy is age-hardenable by formation of Ni2 (Cr,Mo,W) domains, which are structurally similar to the strengthening domains in 242® alloy. Judicious alloying with tungsten increased the thermal stability of these domains and lowered the coefficient of thermal expansion. Other important properties such as oxidation resistance and low-cycle fatigue performance are comparable or better than those of 242® alloy.

Nominal Composition

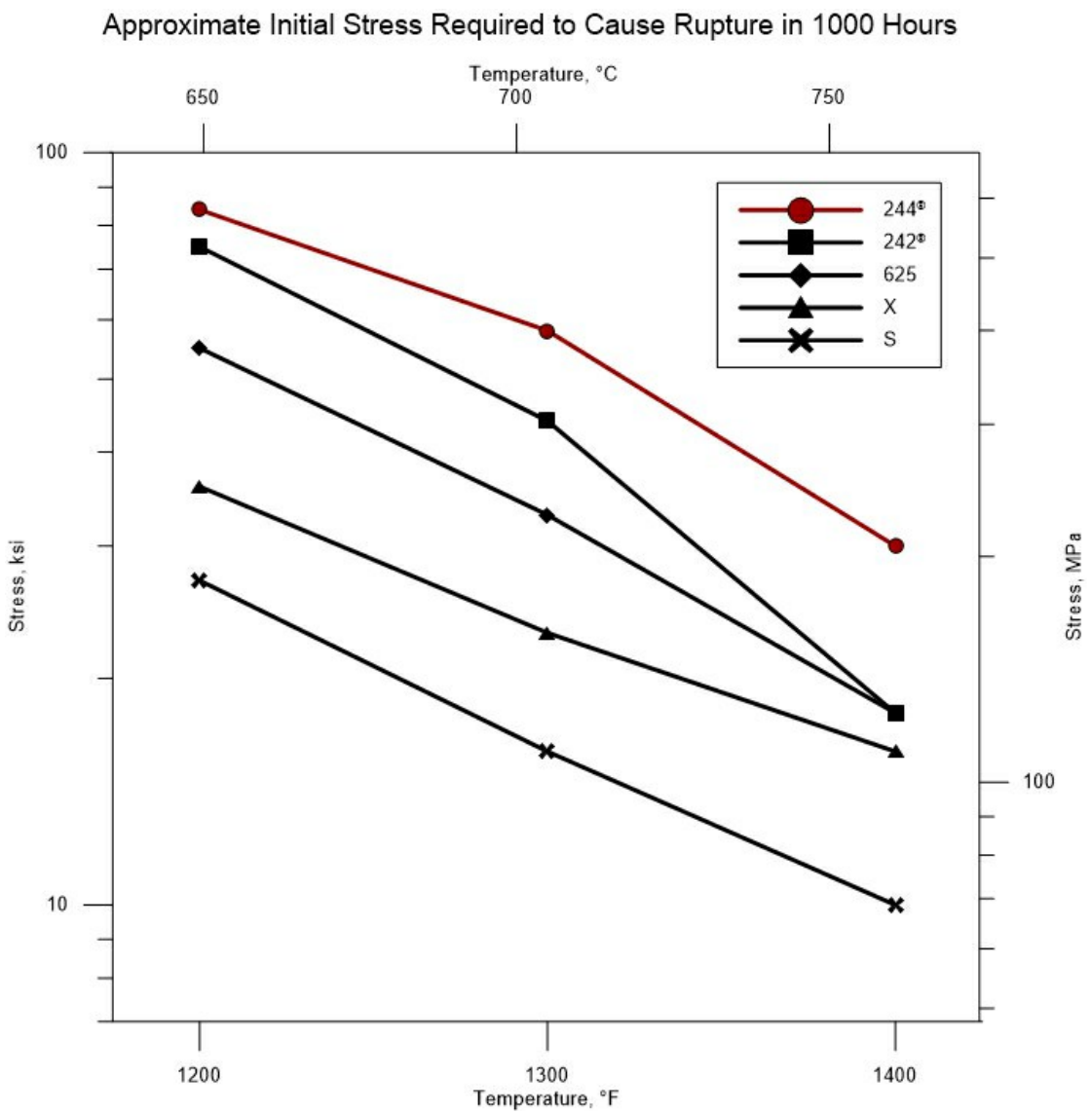
	Weight %
Nickel:	Balance
Aluminum:	0.5 max.
Carbon:	0.03 max.
Chromium:	8
Iron:	2 max.
Manganese:	0.8 max.
Molybdenum:	22.5
Tungsten:	6

Coefficient of Thermal Expansion



*244® Thermal Expansion data can be found on the Physical Properties page

Creep and Stress-Rupture Strength

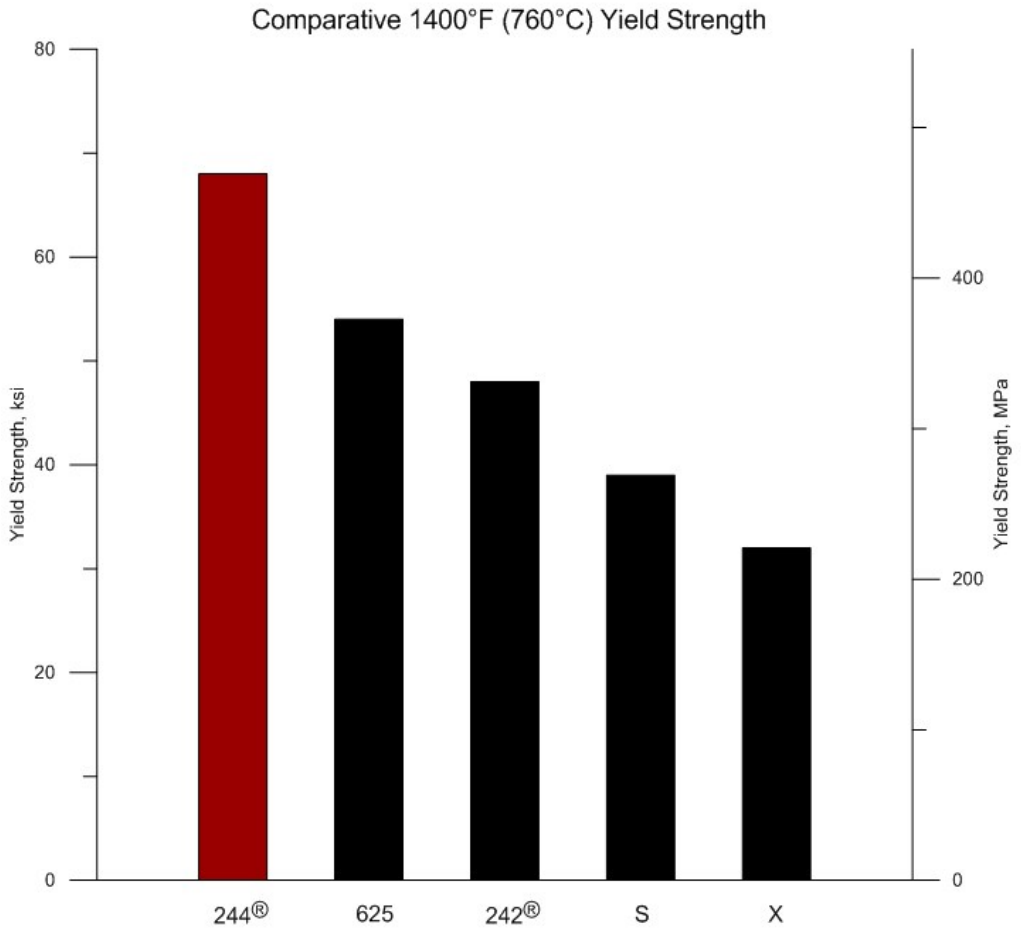


244® Plate, Age-Hardened (Limited Data)

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	1	-	-	92	634	75	517	58*	400*
		R	102	703	93	641	84	579	65	448
1300	704	1	80	552	62	427	49	338	35	241
		R	92	634	74	510	58	400	39	269
1400	760	1	47	324	34	234	25	172	13*	90*
		R	58	400	43	296	30	207	18	124

*Significant extrapolation

Tensile Properties



244® Alloy Plate

Test Temperature		Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elongation	Reduction in Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	123.3	850	196.6	1356	33	37
200	93	115.8*	789*	190.7*	1315*	39*	43*
400	204	109.6*	756*	181.4*	1251*	40*	47*
600	316	103.1*	711*	174.9*	1206*	42*	47*
800	427	98.9	682	171.1	1179	42	47
1000	538	103.3	712	167.3	1153	34	37
1100	593	95.7*	660*	155.6*	1073*	37*	46*
1200	649	94.0	648	140.0	965	21	25
1300	705	86.0	593	124.6	859	16	21
1400	760	68.0	469	105.4	726	40	36
1500	816	36.1*	249*	72.2*	498*	96.5*	65.3*
1600	871	36.5*	252*	54.9*	379*	120*	84*
1800	982	25.9*	179*	33.9*	234*	150*	98*

RT= Room Temperature

Solution annealed + aged 1400°F / 16 h / furnace cool to 1200°F / 32 h / air cool

*Single test

244® Alloy Sheet, Limited Data

Test Temperature		Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	129.6	894	201.2	1387	35
200	93	128.0	883	195.0	1345	33
400	204	123.0	848	191.5	1320	35
600	316	114.0	786	187.5	1293	41
800	427	112.5	776	181.5	1251	39
1000	538	110.5	762	171.0	1179	30
1100	593	109.5	755	160.0	1103	18.0
1200	649	105.5	727	147.5	1017	12
1300	704	91.2	629	125.3	864	9.0
1400	760	78.4	541	113.0	779	20
1500	816	42.6	294	70.6	487	95.0
1600	871	41.8	288	53.8	371	118
1800	982	16.9	117	25.2	174	103

RT= Room Temperature

Solution annealed + aged 1400°F / 16 h / furnace cool to 1200°F / 32 h / air cool

244® Alloy, Rings

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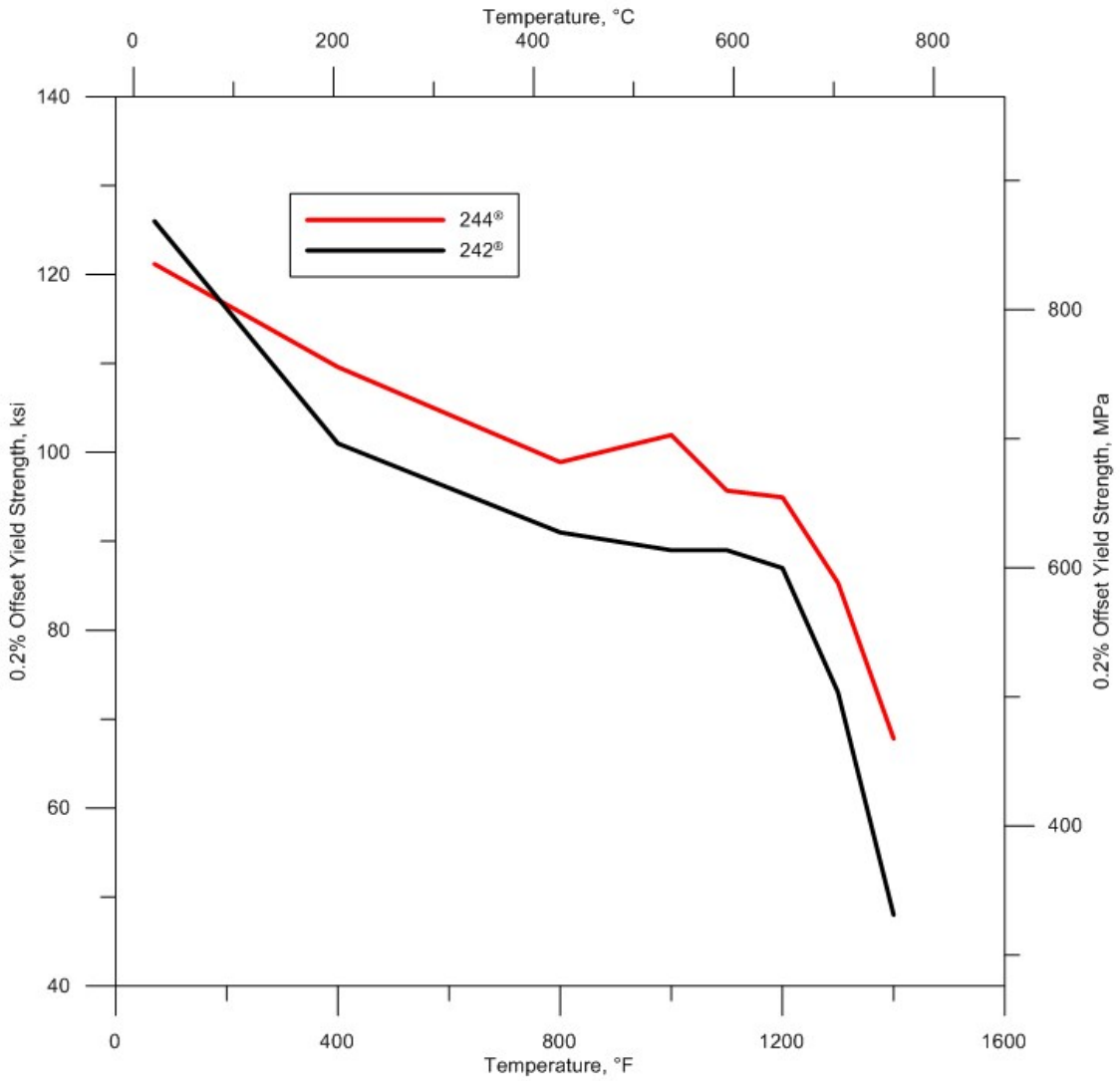
Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction in Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	130.9	902	205.1	1414	29.6	32.3
1400	760	74.1	511	111	765	53.5	50

RT= Room Temperature

Solution annealed + aged 1400°F / 16 h / furnace cool to 1200°F / 32 h / air cool

Comparison of 244® and 242® 0.2% Offset Yield Strengths



Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.335 lb/in^3	RT	9.27 g/cm^3
Melting Range	2480-2550°F	-	1360-1400°C	-

Electrical Resistivity	RT	38.9 µohm-in	RT	98.9 µohm-cm
	200°F	40.0 µohm-in	100°C	101.7 µohm-cm
	400°F	41.5 µohm-in	200°C	105.1 µohm-cm
	600°F	42.8 µohm-in	300°C	108.3 µohm-cm
	800°F	44.2 µohm-in	400°C	111.4 µohm-cm
	1000°F	45.5 µohm-in	500°C	114.4 µohm-cm
	1200°F	46.4 µohm-in	600°C	117.5 µohm-cm
	1400°F	49.4 µohm-in	700°C	119.8 µohm-cm
	1600°F	51.6 µohm-in	800°C	128.8 µohm-cm
	1800°F	50.5 µohm-in	900°C	130.1 µohm-cm
Thermal Diffusivity	RT	5.5×10^{-3} in^2/s	RT	35.5×10^{-3} cm^2/s
	125°F	5.8×10^{-3} in^2/s	100°C	38.3×10^{-3} cm^2/s
	200°F	5.9×10^{-3} in^2/s	200°C	41.1×10^{-3} cm^2/s
	400°F	6.4×10^{-3} in^2/s	300°C	44.1×10^{-3} cm^2/s
	600°F	6.9×10^{-3} in^2/s	400°C	47.4×10^{-3} cm^2/s
	800°F	7.5×10^{-3} in^2/s	500°C	50.5×10^{-3} cm^2/s
	1000°F	8.0×10^{-3} in^2/s	600°C	53.4×10^{-3} cm^2/s
	1200°F	8.5×10^{-3} in^2/s	700°C	55.4×10^{-3} cm^2/s
	1400°F	8.7×10^{-3} in^2/s	800°C	53.1×10^{-3} cm^2/s
	1600°F	7.4×10^{-3} in^2/s	900°C	48.2×10^{-3} cm^2/s
	1800°F	7.7×10^{-3} in^2/s	-	-
Thermal Conductivity	RT	86.2 BTU-in/ft^2-hr-°F	RT	12.4 W/m-ºC
	200°F	94.8 BTU-in/ft^2-hr-°F	100°C	13.8 W/m-ºC
	400°F	106.9 BTU-in/ft^2-hr-°F	200°C	15.3 W/m-ºC
	600°F	120.9 BTU-in/ft^2-hr-°F	300°C	17.1 W/m-ºC
	800°F	134.2 BTU-in/ft^2-hr-°F	400°C	18.9 W/m-ºC
	1000°F	144.8 BTU-in/ft^2-hr-°F	500°C	20.4 W/m-ºC
	1200°F	171.5 BTU-in/ft^2-hr-°F	600°C	23.0 W/m-ºC
	1400°F	308.3 BTU-in/ft^2-hr-°F	700°C	33.8 W/m-ºC
	1600°F	164.5 BTU-in/ft^2-hr-°F	800°C	37.0 W/m-ºC
	1800°F	142.7 BTU-in/ft^2-hr-°F	900°C	22.9 W/m-ºC

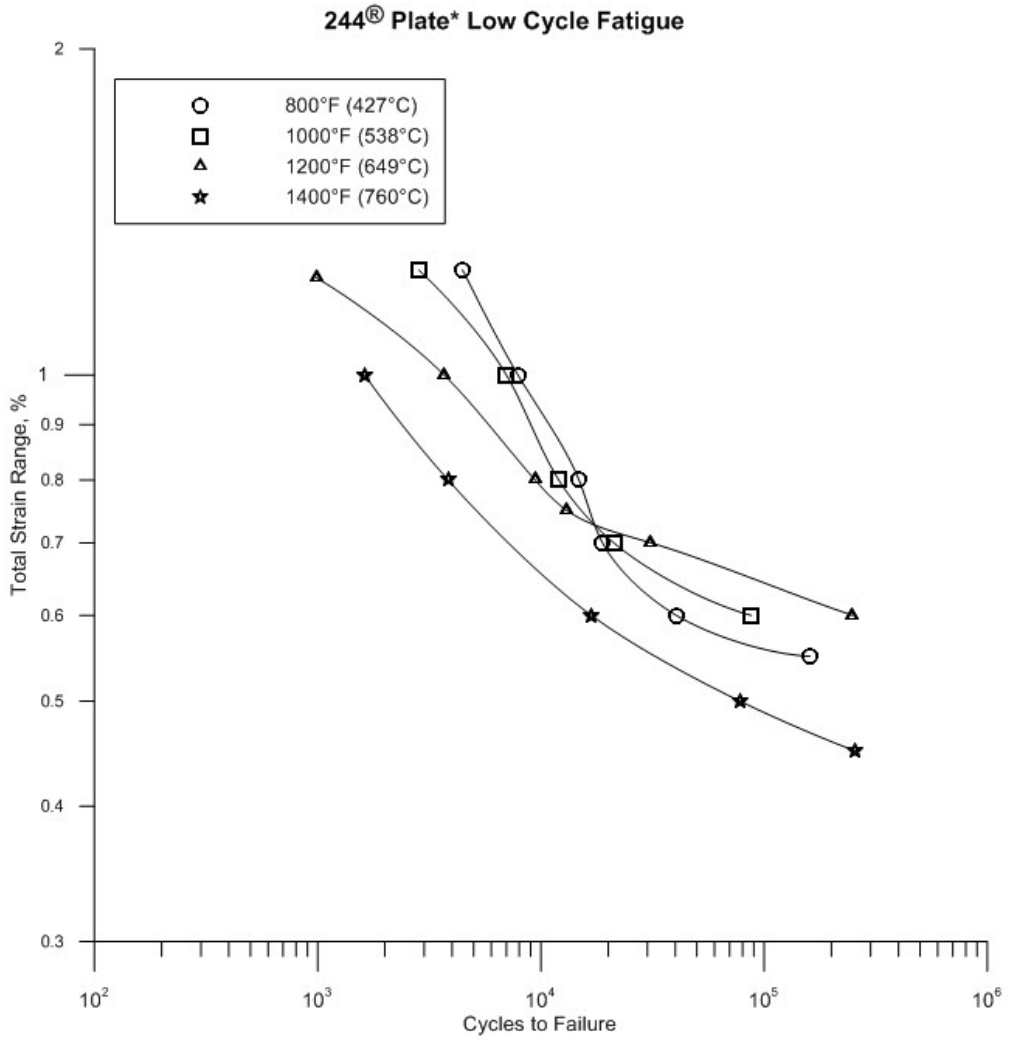
Specific Heat	RT	0.090 BTU/lb-°F	RT	376 J/kg-ºC
	200°F	0.093 BTU/lb-°F	100°C	389 J/kg-ºC
	400°F	0.096 BTU/lb-°F	200°C	404 J/kg-ºC
	600°F	0.100 BTU/lb-°F	300°C	416 J/kg-ºC
	800°F	0.103 BTU/lb-°F	400°C	427 J/kg-ºC
	1000°F	0.104 BTU/lb-°F	500°C	438 J/kg-ºC
	1200°F	0.116 BTU/lb-°F	600°C	428 J/kg-ºC
	1400°F	0.204 BTU/lb-°F	700°C	588 J/kg-ºC
	1600°F	0.127 BTU/lb-°F	800°C	852 J/kg-ºC
	1800°F	0.106 BTU/lb-°F	900°C	480 J/kg-ºC
Mean Coefficient of Thermal Expansion	70-200°F	5.93 µin/in-°F	25-100°C	10.7 µm/m-°C
	70-400°F	6.11 µin/in-°F	25-200°C	11.0 µm/m-°C
	70-600°F	6.26 µin/in-°F	25-300°C	11.2 µm/m-°C
	70-800°F	6.40 µin/in-°F	25-400°C	11.5 µm/m-°C
	70-1000°F	6.54 µin/in-°F	25-500°C	11.7 µm/m-°C
	70-1100°F	6.57 µin/in-°F	25-550°C	11.8 µm/m-°C
	70-1200°F	6.70 µin/in-°F	25-600°C	11.9 µm/m-°C
	70-1300°F	6.97 µin/in-°F	25-650°C	12.1 µm/m-°C
	70-1400°F	7.39 µin/in-°F	25-700°C	12.5 µm/m-°C
	70-1500°F	7.78 µin/in-°F	25-750°C	13.2 µm/m-°C
	70-1600°F	7.95 µin/in-°F	25-800°C	13.8 µm/m-°C
	70-1800°F	8.22 µin/in-°F	25-900°C	14.4 µm/m-°C
Dynamic Modulus of Elasticity	RT	32.3 x 10^6psi	RT	223 GPa
	200°F	31.9 x 10^6psi	100°C	220 GPa
	400°F	30.8 x 10^6psi	200°C	213 GPa
	600°F	29.7 x 10^6psi	300°C	206 GPa
	800°F	28.7 x 10^6psi	400°C	199 GPa
	1000°F	27.7 x 10^6psi	500°C	193 GPa
	1200°F	26.6 x 10^6psi	600°C	186 GPa
	1400°F	23.9 x 10^6psi	700°C	175 GPa
	1600°F	21.9 x 10^6psi	800°C	159 GPa
	1800°F	20.6 x 10^6psi	900°C	150 GPa
Dynamic Shear Modulus	RT	12.4 x 10^6psi	RT	85 GPa
	200°F	12.2 x 10^6psi	100°C	84 GPa
	400°F	11.7 x 10^6psi	200°C	81 GPa
	600°F	11.2 x 10^6psi	300°C	78 GPa
	800°F	10.8 x 10^6psi	400°C	75 GPa
	1000°F	10.4 x 10^6psi	500°C	73 GPa
	1200°F	10.1 x 10^6psi	600°C	70 GPa
	1400°F	9.2 x 10^6psi	700°C	68 GPa
	1600°F	8.7 x 10^6psi	800°C	62 GPa
	1800°F	7.4 x 10^6psi	900°C	59 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	0.32
	1000°F	0.33	500°C	0.33
	1200°F	0.32	600°C	0.33
	1400°F	0.30	700°C	0.30
	1600°F	0.28	800°C	0.29
	1800°F	0.27	900°C	0.26

All properties measured as solution annealed + aged 1400°F / 16 h / furnace cool to 1200°F / 32h / air cool

Low Cycle Fatigue

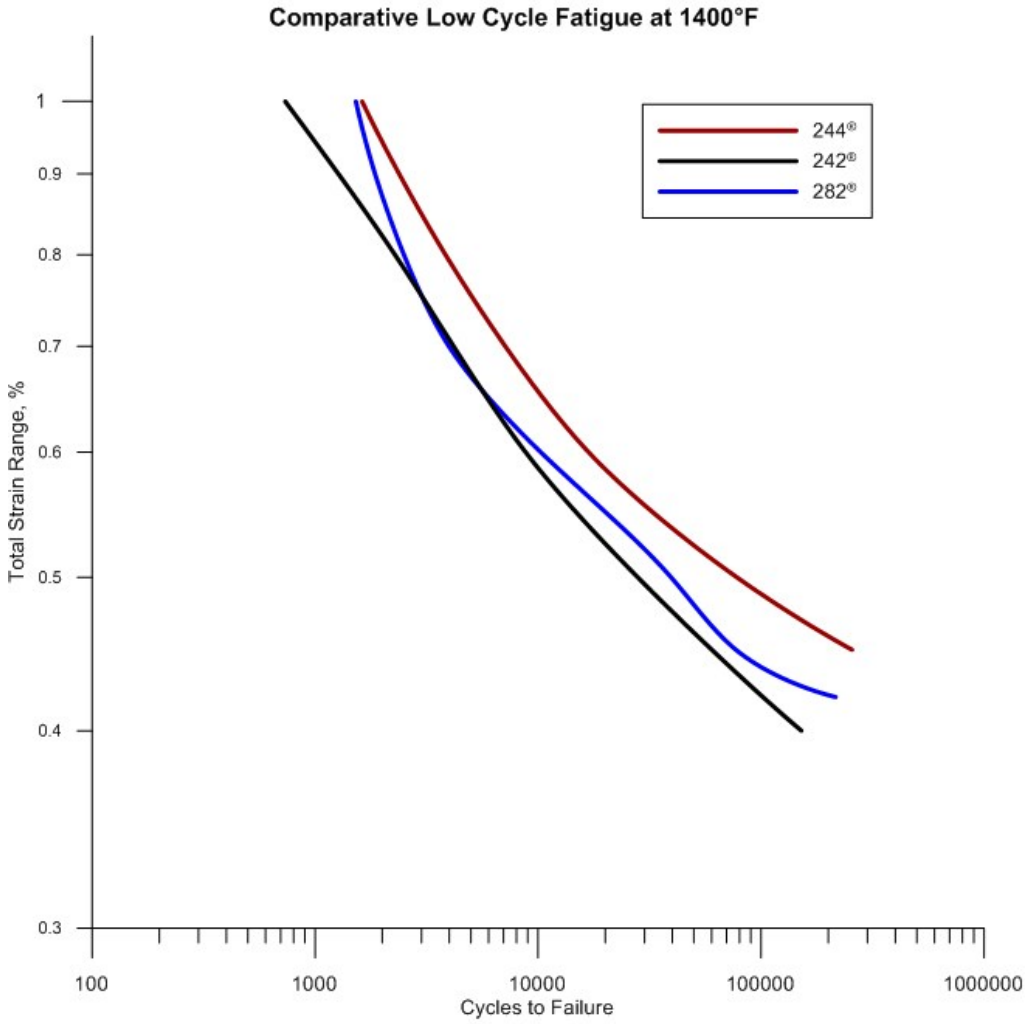
HAYNES® 244® alloy exhibits excellent low cycle fatigue properties at elevated temperature. Results shown below are for strain-controlled tests run in the temperature range from 800 to 1400°F (425 to 760°C). Samples were machined from plate. Tests were run with fully reversed strain (R=-1) at a frequency of 20 cpm (0.33 Hz).



*Solution Annealed + Aged Hardened 1400°F / 16 h / furnace cool to 1200°F / 32 h / air cool

Temperature		$\Delta\varepsilon_{tot}$/%	N_i, Cycles to Initiation	N_f, Cycles to Failure
°F	°C			
800	427	1.25	3,949	4,461
		1.00	6,398	7,889
		0.80	12,380	14,820
		0.70	16,159	18,881
		0.65	36,244	41,256
		0.60	39,419	40,506
		0.55	145,998	160,614
		0.50	N/A	200,826*
1000	538	1.25	2,753	2,835
		1.00	5,520	7,006
		0.80	9,859	12,877
		0.80	10,058	11,169
		0.70	16,291	17,989
		0.70	23,438	24,443
		0.60	82,871	87,701
		0.55	N/A	201,022*
1200	649	1.23	897	983
		1.00	3,644	3,686
		0.80	8,980	9,422
		0.75	12,370	13,066
		0.70	30,898	31,078
		0.60	249,079	249,284
1400	760	1.00	1,460	1,625
		0.80	3,634	3,842
		0.60	16,495	16,858
		0.50	73,906	78,024
		0.45	251,579	255,801
		0.40	N/A	305,391*

*Discontinued



244®: Solution Annealed + Aged Hardened 1400°F / 16 h / furnace cool to 1200°F / 32 h / air cool
242®: Solution Annealed + Aged Hardened 1200°F / 24 h / air cool
282®: Solution Annealed + Aged Hardened 1850°F / 2 h / air cool to 1450°F / 8 h / air cool

Oxidation Resistance

HAYNES® 244® alloy exhibits very good oxidation resistance at temperatures up to 1400°F (760°C), and should not require protective coatings for continuous or intermittent service at these temperatures. The alloy is not specifically designed for use at higher temperatures, but can tolerate short-term exposures.

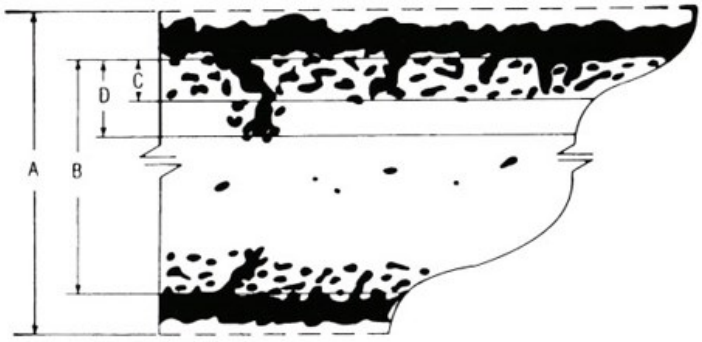
Static Oxidation

Alloy	1400°F (760°C)			
	Metal Loss		Avg. Met. Aff.	
	mils	µm	mils	µm
625	0	0	0	0
244®	**0**	**0**	**0.2**	**5**
242®	0.1	3	0.3	8
R-41	0.1	3	0.4	10
282®	0.1	3	0.4	10
Waspaloy	0.1	3	0.6	15

Comparative Cyclic Oxidation Resistance

Alloy	1400°F (760°C), 1000 h, Cycled 1x/10 h				1400°F (760°C), 1000 h, Cycled 1x/1h			
	Metal Loss		Average Metal Affected		Metal Loss		Average Metal Affected	
	mils	µm	mils	µm	mils	µm	mils	µm
244®	**< 0.1**	**0.6**	**0.1**	**1.9**	**< 0.1**	**0.5**	**0.1**	**3**
242®	< 0.1	0.7	0.1	1.9	< 0.1	0.5	0.1	3
282®	0.1	1.5	0.4	10	0.1	1.5	0.4	10
Waspaloy	0.1	2.2	0.6	15	0.1	2.2	0.6	15

Amount of metal affected for alloys exposed to flowing air for 1000-h at 1400°F. Cycled as noted.



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

Thermal Stability

Thermal Stability of 244® alloy – 1400°F Tensile Data After Exposure, 0.500" Plate

Condition	0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
	ksi	MPa	ksi	MPa	%	%
As-Heat Treated*	68.9	461	103.4	728	33.5	32.4
+1400°F/1,000 hr	71.3	492	111.6	770	36.5	32.5
+1400°F/8,000 hr	62.6	432	102.8	709	60.3	37.2

*Age hardened 1400ºF / 16 h / furnace cool to 1200ºF / 32 h / air cool

Thermal Stability of 244® alloy – Room Temperature Tensile Data After Exposure, 0.500” Plate

Condition	0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
	ksi	MPa	ksi	MPa	%	%
As-Heat Treated*	122.8	847	193.3	1333	34.7	39.2
+ 800°F/1,000 hr	123.3	850	196.2	1353	31.8	37.1
+ 800°F/8,000 hr	128.2	884	200.7	1384	32.3	20.6
+ 1200°F/1,000 hr	122.8	847	204.6	1411	25.5	25.6
+ 1200°F/8,000 hr	122.0	841	205.9	1420	25.4	27.3
+1300°F/1,000 hr	121.1	835	198.7	1370	24.4	26.4
+1300°F/8,000 hr	115.4	796	190.1	1311	15.5	17.0
+1400°F/1,000 hr	97.8	674	159.0	1096	13.1	13.3
+1400°F/8,000 hr	86.1	594	145.9	1006	8.7	6.6

*Age hardened 1400ºF /16h / furnace cool to 1200ºF /32h /air cool

Dimensional Stability

Temper	Density		Linear Change	Additional Linear Change
	lb/in^3	g/cm^3	%	%
Solution Annealed	0.3356	9.290	Reference	Reference
Age Hardened*	0.3370	9.329	-0.14	-
Aged + 800°F/1,000h	0.3371	9.332	-	-0.01
Aged + 800°F/8,000h	0.3372	9.334	-	-0.02
Aged + 1200°F/1,000h	0.3368	9.323	-	+0.02
Aged + 1200°F/8,000h	0.3368	9.323	-	+0.02
Aged + 1300°F/1,000h	0.3367	9.320	-	+0.03
Aged + 1300°F/8,000h	0.3365	9.315	-	+0.04
Aged + 1400°F/1,000h	0.3363	9.309	-	+0.07
Aged + 1400°F/8,000h	0.3364	9.312	-	+0.06

*1400°F / 16 h / furnace cool to 1200°F / 32 h / air cool

Heat Treatment

HAYNES® 244® alloy is furnished in the annealed condition, unless otherwise specified. The alloy is usually annealed in the range of 2000-2100°F (1093-1149°C), depending upon specific requirements, followed by an air cool (or more rapid cooling) before aging. A water quench is recommended for heavy section components. Aging is performed by holding at 1400°F (760°C) for 16 hours, furnace cooling to 1200°F (649°C) and holding for 32 hours, followed by air cool.

Formability

Samples mill annealed and cold worked yielded the following room temperature tensile results:

Cold Work	Yield Strength		Ultimate Tensile Strength		Elongation
%	ksi	MPa	ksi	MPa	%
0	74	510	134	924	57
10	112	772	150	1034	38
20	142	979	167	1151	26
30	168	1158	191	1317	14
40	194	1338	215	1482	8

Welding

HAYNES® 244® alloy can be welded by a variety of processes, including gas tungsten arc and gas metal arc. High heat input processes such as submerged arc and oxyacetalyne welding are not recommended.

Welding Procedures

Welding procedures common to most high-temperature, nickel-base alloys are recommended. These include use of stringer beads and an interpass temperature less than 200°F (95°C). Preheat is not required. Cleanliness is critical, and careful attention should be given to the removal of grease, oil, crayon marks, shop dirt, etc. prior to welding. Because of the alloy's high nickel content, the weld puddle will be somewhat "sluggish" relative to steels. To avoid lack of fusion and incomplete penetration defects, the root opening and bevel should be sufficiently open.

Filler Metals

HAYNES® 244® alloy should be joined using matching filler metal. Please contact Haynes International for more information.

Postweld Heat Treatment

HAYNES® 244® alloy is normally used in the fully-aged condition. However, following forming and welding, a full solution anneal is recommended prior to aging in order to develop the best joint and overall mechanical properties.

Transverse Weld Tensile Results, GTAW & GMAW of 0.5” plate with 0.045” dia. 244® filler metal

Condition	Temperature		0.2% Yield Strength		Ultimate Tensile Data		Elongation	Reduction of Area	Failure Location
	°F	°C	ksi	MPa	ksi	MPa	%	%	
GTAW + Solution Annealed* + Age Hardened**	RT	RT	120.4	830	184.7	1273	18	19	Weld Metal
	1200	649	93.4	644	135.5	934	14	18	Weld Metal
	1300	704	83.9	578	119.1	821	13	17	Weld Metal
	1400	760	67.8	467	105.1	725	32	22	Weld Metal
GMAW + Solution Annealed* + Age Hardened**	RT	RT	121.3	836	187.0	1289	19	14	Weld Metal
	1200	649	95.7	660	129.1	890	14	25	Base Metal
	1300	704	84.8	585	117.8	812	17	20	Base Metal
	1400	760	68.2	470	105.6	728	30	26	Weld Metal

*Annealing treatment: 2050°F / 30 minutes AT / water quench

**Age hardening treatment: 1400°F / 16 hr / FC to 1200°F / 32 hr / air cool

Disclaimer