

HAYNES® 244® Alloy

Principal Features

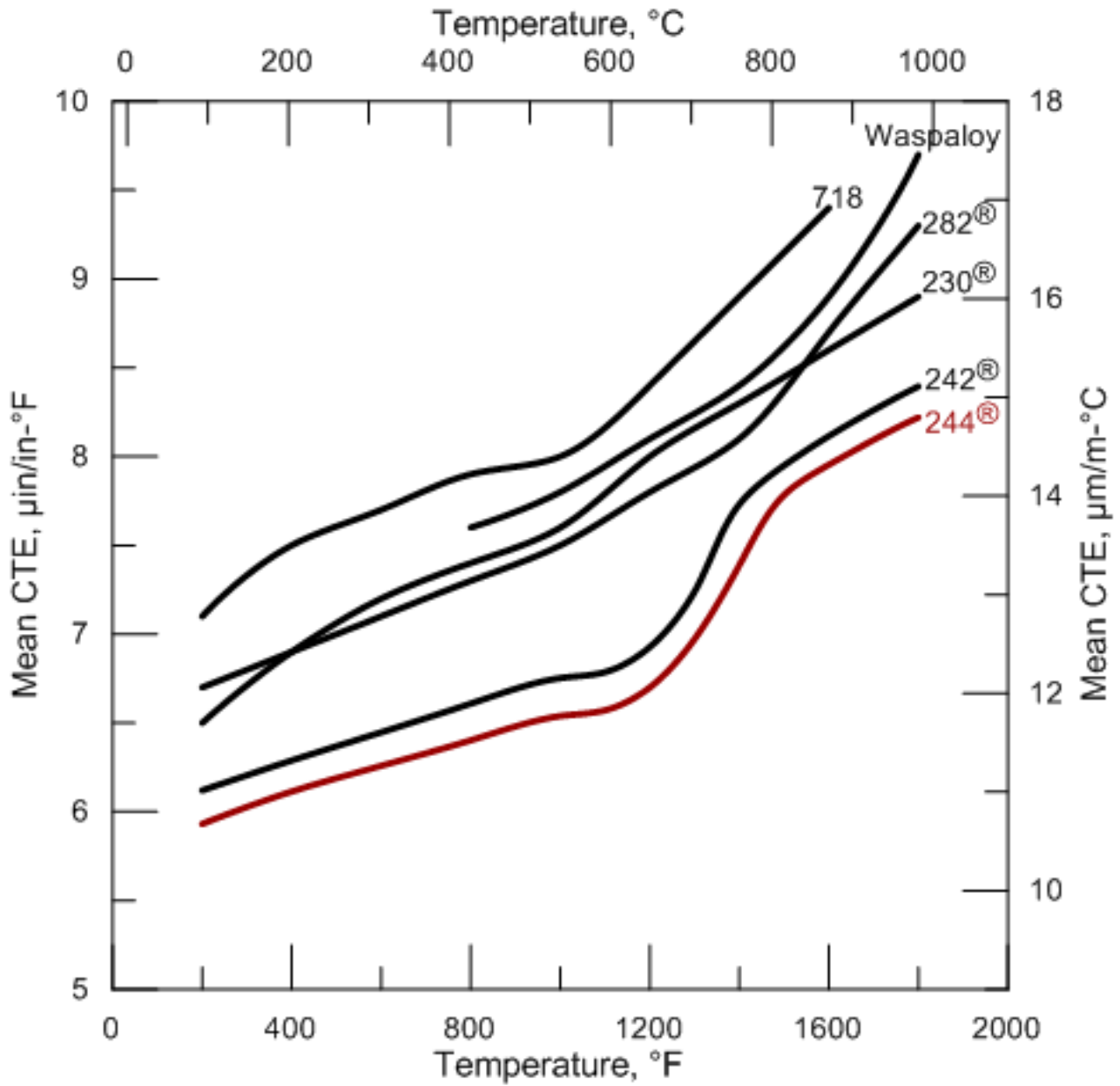
HAYNES® 244® alloy is a new Ni-Mo-Cr-W alloy developed for static parts in advanced gas turbine engines which require low thermal expansion at temperatures up to 1400°F (760°C). It offers a higher maximum use temperature than other low thermal expansion alloys currently available, including a 100-200°F (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

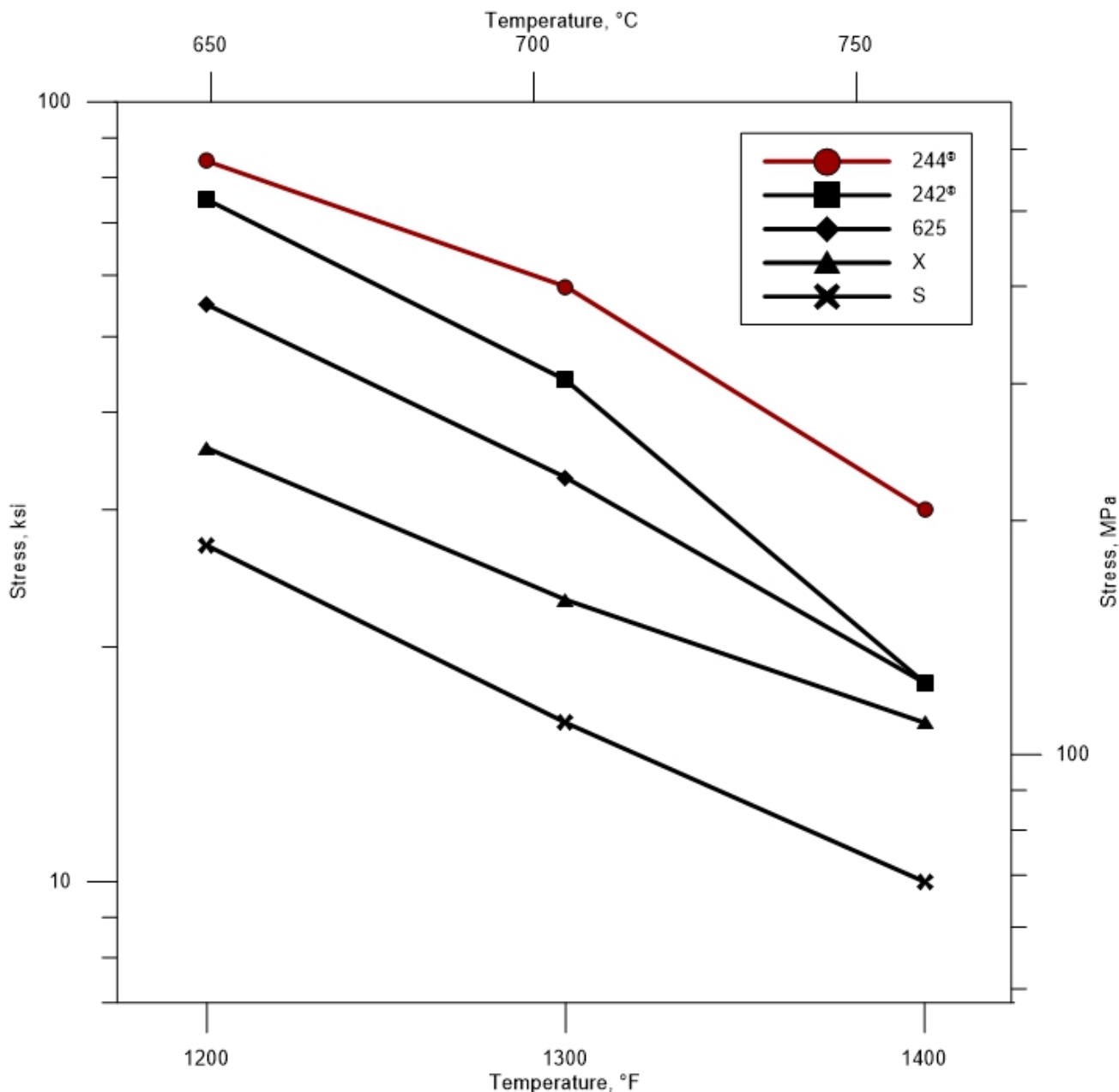
Coefficient of Thermal Expansion



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

Creep and Stress-Rupture Strength

Approximate Initial Stress Required to Cause Rupture in 1000 Hours

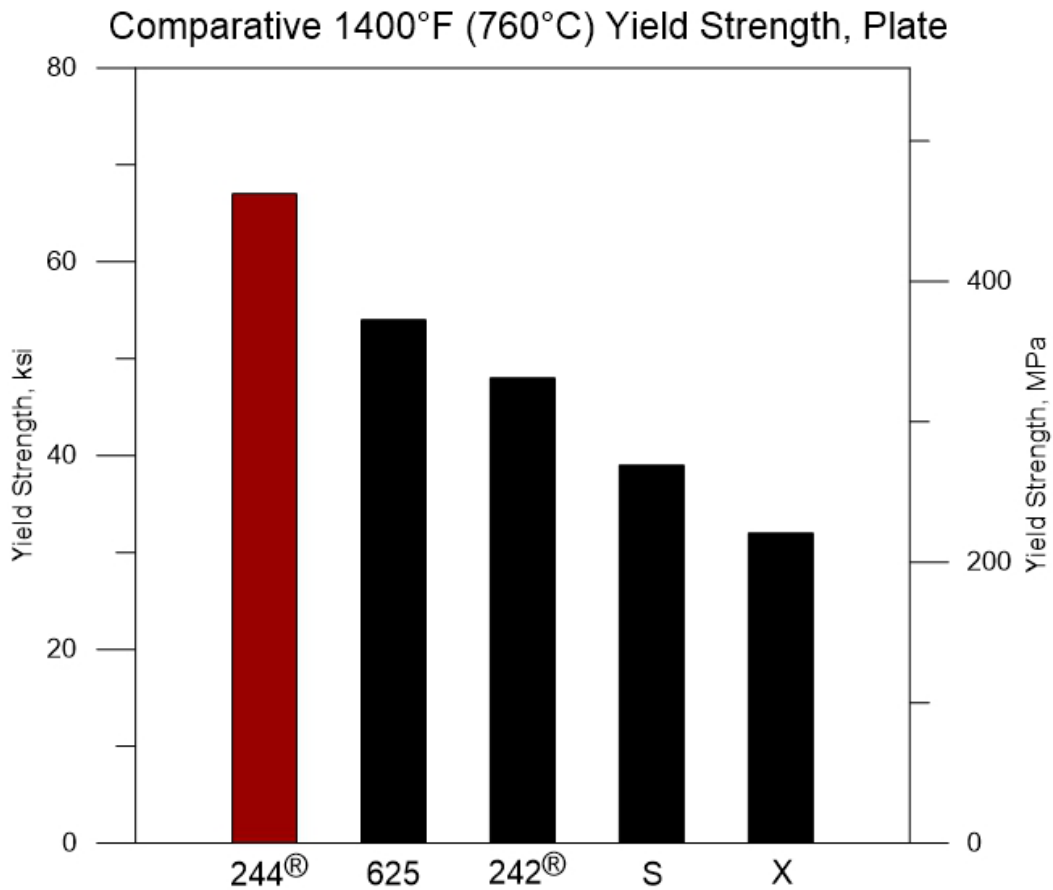


244[®] Plate, Age-Hardened (Limited Data)

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		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	121.2	836	195.0	1345	34	37
200	93	116.3	802	190.3	1312	39	41
400	204	110.3	761	181.6	1252	39	45
600	316	107.9	744	175.4	1209	41	44
800	427	100.0	689	170.4	1175	41	46
1000	538	99.3	685	164.2	1132	38	43
1100	593	97.5	672	156.3	1078	32	32
1200	649	93.8	647	141.4	975	21	24
1300	704	84.8	585	125.6	866	18	20
1400	760	67.2	463	105.0	696	44	37
1500	816	37.1	256	72.0	463	106	70
1600	871	34.8	240	54.1	354	124	84
1700	927	38.2*	263*	42.4*	208*	161*	89*
1800	983	24.0	165	30.4	210	141	94

*Single test

Tensile Properties Continued

244® Alloy Sheet

Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	125.2	863	191.7	1322	28
200	94	128.0*	883*	195.0*	1345*	33*
400	205	123.0*	848*	191.5*	1320*	35*
600	316	114.1*	786*	187.5*	1293*	41*
800	427	112.5*	776*	181.5*	1251*	39*
1000	538	101.4	699	159.8	1101	28
1100	594	102.6	707	153.9	1061	19
1200	649	96.1	663	135.9	937	14
1300	705	87.2	601	118.3	815	9
1400	761	68.9	475	103.8	716	31
1500	816	37.6	259	69.3	477	78
1600	872	41.8*	288*	53.8*	371*	118*
1700	927	31.2*	215*	41.1*	283*	103*
1800	983	16.9*	117*	25.2*	174*	103*

*Single test

244® Alloy Bar

Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	130.0	896	202.3	1395	34	38
200	22	121.1*	835*	195.2*	1346*	38*	39*
400	114	120.0	827	189.5	1306	37	42
600	169	123.8	853	184.5	1272	39	43
800	225	111.4	768	179.9	1240	40	41
1000	280	121.3	836	170.3	1174	33	38
1100	308	114.5	789	160.9	1109	20	19
1200	336	103.6	714	146.3	1009	15	20
1300	364	93.3	643	130.6	900	15	21
1400	391	75.1	518	110.2	759	25	25
1500	419	34.6	238	73.5	506	67	48
1600	447	37.3	257	54.9	379	94	64
1800	983	19.2*	132*	28.7*	198*	150*	89*

*Single test

Tensile Properties Continued

244[®] Alloy Rings

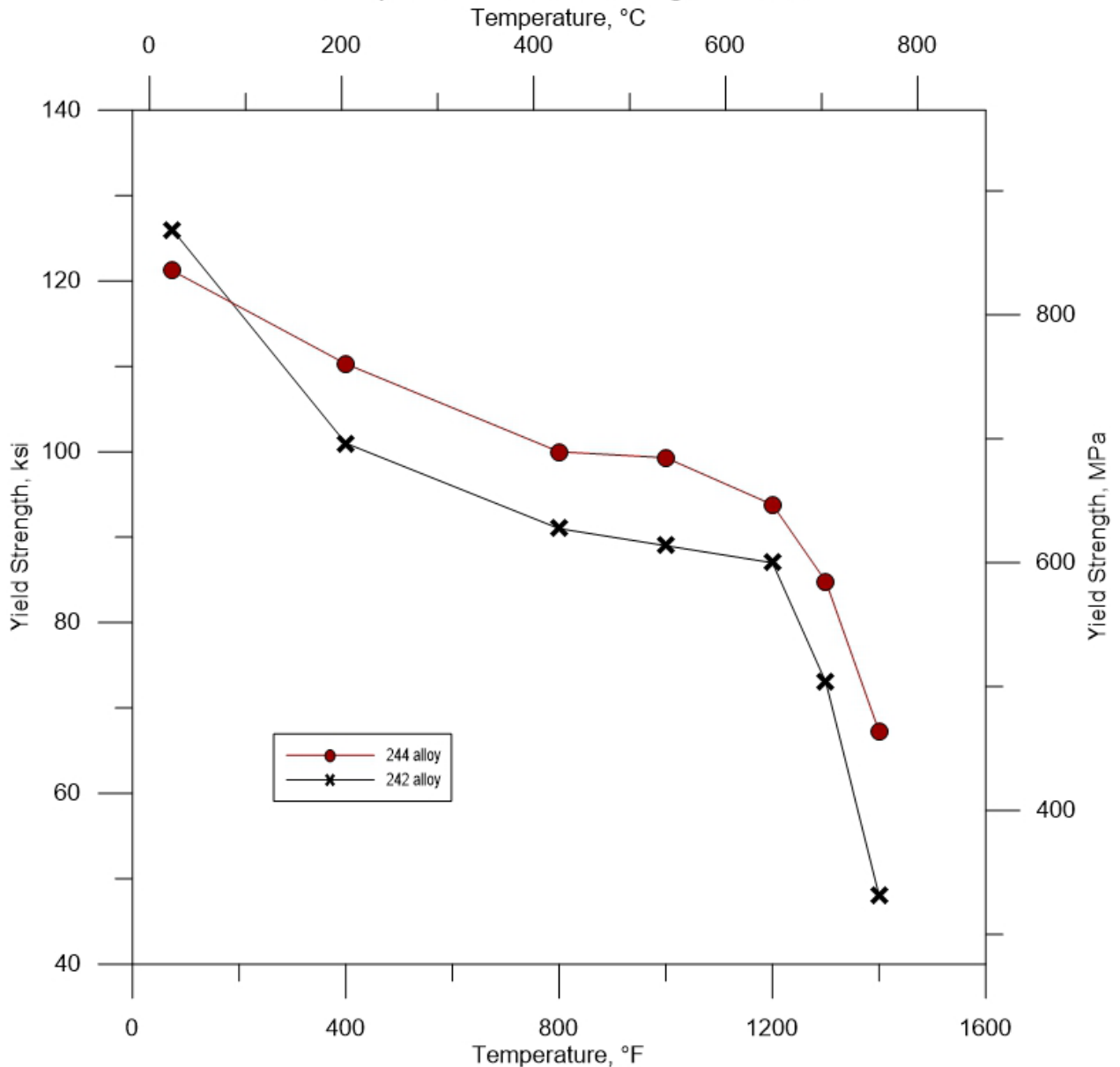
Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction in Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	130.9	902	205.1	1414	29.6	32.3
1400	760	74.1	511	111	765	53.5	50

RT= Room Temperature

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

Comparison of 244[®] and 242[®] Yield Strengths

Comparative Yield Strength, Plate



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 x 10 ⁻³ in ² /s	RT	35.5 x 10 ⁻³ cm ² /s
	125°F	5.8 x 10 ⁻³ in ² /s	100°C	38.3 x 10 ⁻³ cm ² /s
	200°F	5.9 x 10 ⁻³ in ² /s	200°C	41.1 x 10 ⁻³ cm ² /s
	400°F	6.4 x 10 ⁻³ in ² /s	300°C	44.1 x 10 ⁻³ cm ² /s
	600°F	6.9 x 10 ⁻³ in ² /s	400°C	47.4 x 10 ⁻³ cm ² /s
	800°F	7.5 x 10 ⁻³ in ² /s	500°C	50.5 x 10 ⁻³ cm ² /s
	1000°F	8.0 x 10 ⁻³ in ² /s	600°C	53.4 x 10 ⁻³ cm ² /s
	1200°F	8.5 x 10 ⁻³ in ² /s	700°C	55.4 x 10 ⁻³ cm ² /s
	1400°F	8.7 x 10 ⁻³ in ² /s	800°C	53.1 x 10 ⁻³ cm ² /s
	1600°F	7.4 x 10 ⁻³ in ² /s	900°C	48.2 x 10 ⁻³ cm ² /s
	1800°F	7.7 x 10 ⁻³ in ² /s	-	-
Thermal Conductivity	RT	86.2 BTU-in/ft ² -hr-°F	RT	12.4 W/m-°C
	200°F	94.8 BTU-in/ft ² -hr-°F	100°C	13.8 W/m-°C
	400°F	106.9 BTU-in/ft ² -hr-°F	200°C	15.3 W/m-°C
	600°F	120.9 BTU-in/ft ² -hr-°F	300°C	17.1 W/m-°C
	800°F	134.2 BTU-in/ft ² -hr-°F	400°C	18.9 W/m-°C
	1000°F	144.8 BTU-in/ft ² -hr-°F	500°C	20.4 W/m-°C
	1200°F	171.5 BTU-in/ft ² -hr-°F	600°C	23.0 W/m-°C
	1400°F	308.3 BTU-in/ft ² -hr-°F	700°C	33.8 W/m-°C
	1600°F	164.5 BTU-in/ft ² -hr-°F	800°C	37.0 W/m-°C
	1800°F	142.7 BTU-in/ft ² -hr-°F	900°C	22.9 W/m-°C

Physical Properties Continued

Physical Property	British Units		Metric Units	
Specific Heat	RT	0.090 BTU/lb-°F	RT	376 J/kg-°C
	200°F	0.093 BTU/lb-°F	100°C	389 J/kg-°C
	400°F	0.096 BTU/lb-°F	200°C	404 J/kg-°C
	600°F	0.100 BTU/lb-°F	300°C	416 J/kg-°C
	800°F	0.103 BTU/lb-°F	400°C	427 J/kg-°C
	1000°F	0.104 BTU/lb-°F	500°C	438 J/kg-°C
	1200°F	0.116 BTU/lb-°F	600°C	428 J/kg-°C
	1400°F	0.204 BTU/lb-°F	700°C	588 J/kg-°C
	1600°F	0.127 BTU/lb-°F	800°C	852 J/kg-°C
	1800°F	0.106 BTU/lb-°F	900°C	480 J/kg-°C
Mean Coefficient of Thermal Expansion	70-200°F	5.93 $\mu\text{in/in-}^\circ\text{F}$	25-100°C	10.7 $\mu\text{m/m-}^\circ\text{C}$
	70-400°F	6.11 $\mu\text{in/in-}^\circ\text{F}$	25-200°C	11.0 $\mu\text{m/m-}^\circ\text{C}$
	70-600°F	6.26 $\mu\text{in/in-}^\circ\text{F}$	25-300°C	11.2 $\mu\text{m/m-}^\circ\text{C}$
	70-800°F	6.40 $\mu\text{in/in-}^\circ\text{F}$	25-400°C	11.5 $\mu\text{m/m-}^\circ\text{C}$
	70-1000°F	6.54 $\mu\text{in/in-}^\circ\text{F}$	25-500°C	11.7 $\mu\text{m/m-}^\circ\text{C}$
	70-1100°F	6.57 $\mu\text{in/in-}^\circ\text{F}$	25-550°C	11.8 $\mu\text{m/m-}^\circ\text{C}$
	70-1200°F	6.70 $\mu\text{in/in-}^\circ\text{F}$	25-600°C	11.9 $\mu\text{m/m-}^\circ\text{C}$
	70-1300°F	6.97 $\mu\text{in/in-}^\circ\text{F}$	25-650°C	12.1 $\mu\text{m/m-}^\circ\text{C}$
	70-1400°F	7.39 $\mu\text{in/in-}^\circ\text{F}$	25-700°C	12.5 $\mu\text{m/m-}^\circ\text{C}$
	70-1500°F	7.78 $\mu\text{in/in-}^\circ\text{F}$	25-750°C	13.2 $\mu\text{m/m-}^\circ\text{C}$
	70-1600°F	7.95 $\mu\text{in/in-}^\circ\text{F}$	25-800°C	13.8 $\mu\text{m/m-}^\circ\text{C}$
	70-1800°F	8.22 $\mu\text{in/in-}^\circ\text{F}$	25-900°C	14.4 $\mu\text{m/m-}^\circ\text{C}$
Dynamic Modulus of Elasticity	RT	32.3 x 10 ⁶ psi	RT	223 GPa
	200°F	31.9 x 10 ⁶ psi	100°C	220 GPa
	400°F	30.8 x 10 ⁶ psi	200°C	213 GPa
	600°F	29.7 x 10 ⁶ psi	300°C	206 GPa
	800°F	28.7 x 10 ⁶ psi	400°C	199 GPa
	1000°F	27.7 x 10 ⁶ psi	500°C	193 GPa
	1200°F	26.6 x 10 ⁶ psi	600°C	186 GPa
	1400°F	23.9 x 10 ⁶ psi	700°C	175 GPa
	1600°F	21.9 x 10 ⁶ psi	800°C	159 GPa
	1800°F	20.6 x 10 ⁶ psi	900°C	150 GPa

Physical Properties Continued

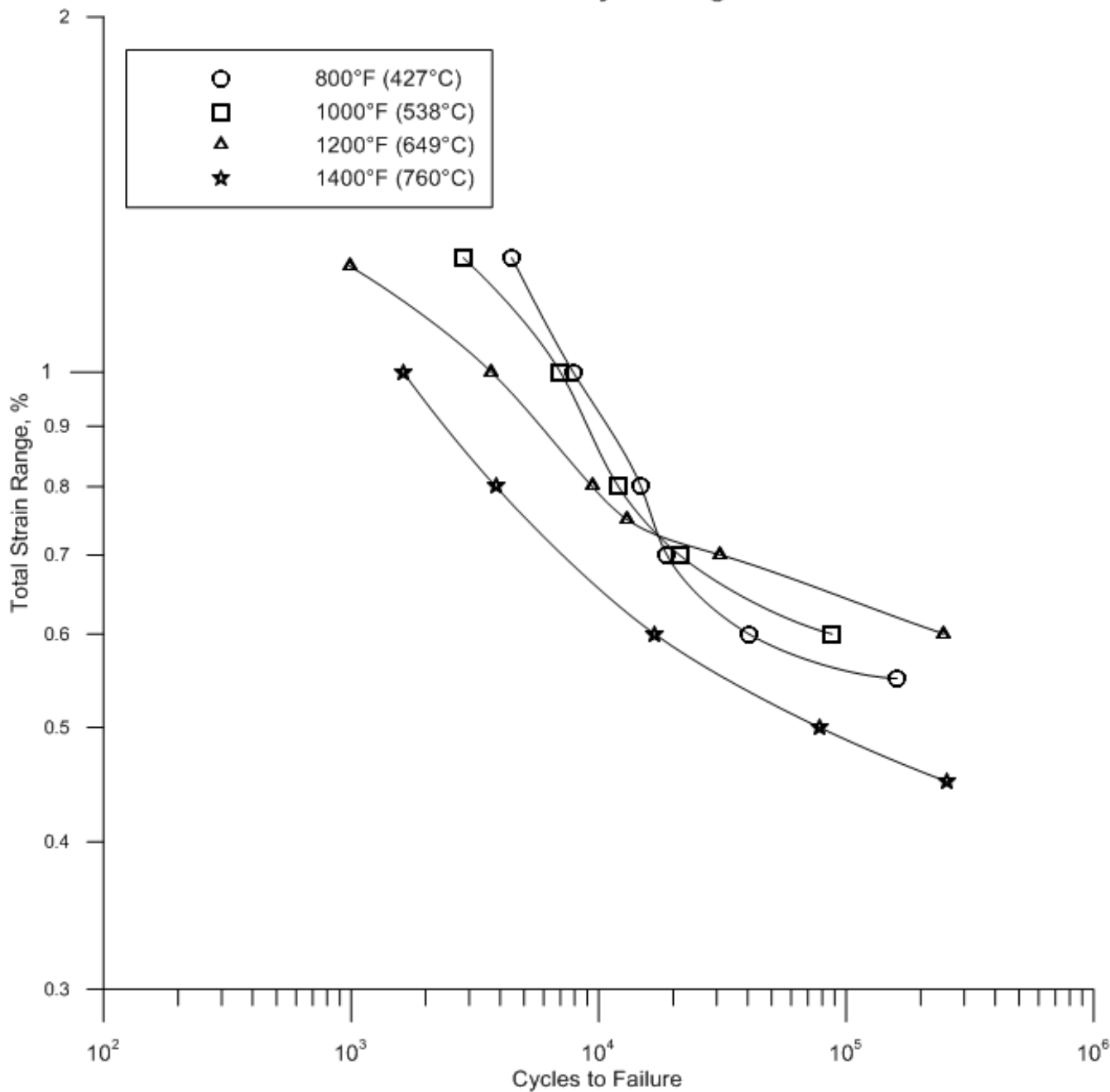
Physical Property	British Units		Metric Units	
Dynamic Shear Modulus	RT	12.4 x 10 ⁶ psi	RT	85 GPa
	200°F	12.2 x 10 ⁶ psi	100°C	84 GPa
	400°F	11.7 x 10 ⁶ psi	200°C	81 GPa
	600°F	11.2 x 10 ⁶ psi	300°C	78 GPa
	800°F	10.8 x 10 ⁶ psi	400°C	75 GPa
	1000°F	10.4 x 10 ⁶ psi	500°C	73 GPa
	1200°F	10.1 x 10 ⁶ psi	600°C	70 GPa
	1400°F	9.2 x 10 ⁶ psi	700°C	68 GPa
	1600°F	8.7 x 10 ⁶ psi	800°C	62 GPa
	1800°F	7.4 x 10 ⁶ psi	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).

244® Plate* Low Cycle Fatigue



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

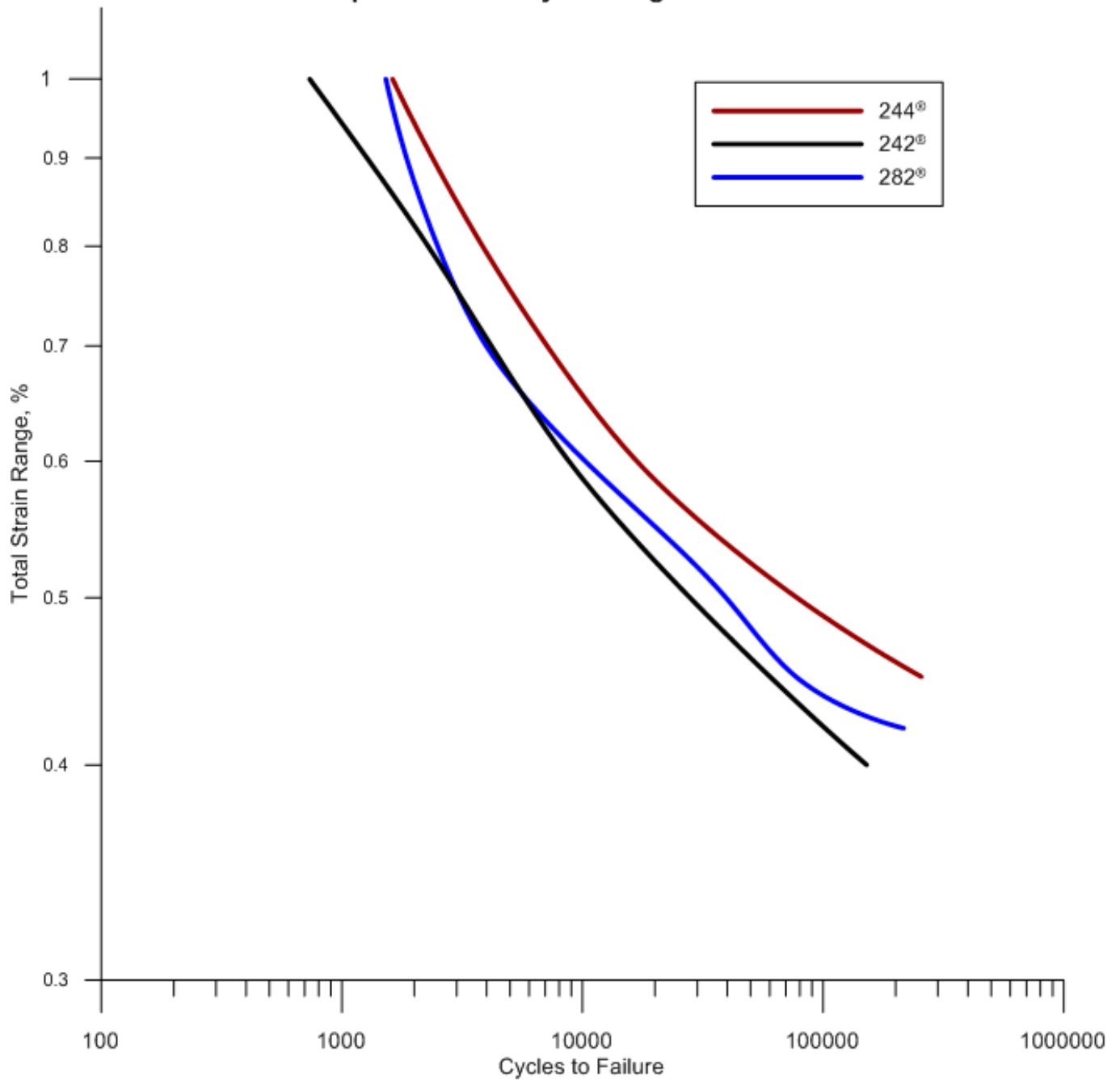
Low Cycle Fatigue Continued

Temperature		$\Delta\epsilon_{tot}/\%$	Ni, Cycles to Initiation	Nf, 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

Low Cycle Fatigue Continued

Comparative Low Cycle Fatigue at 1400°F



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.

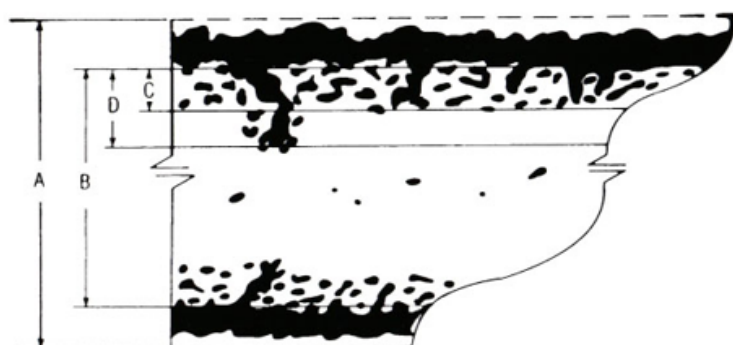
Static Oxidation

Alloy	1400°F (760°C)			
	Metal Loss		Average Metal Affected	
	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 1400°F / 16 h / furnace cool to 1200°F / 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	1096	13.1	13.3
+1400°F/8,000 hr	86.1	594	145.9	1006	8.7	6.6

*Age hardened 1400°F /16h / furnace cool to 1200°F / 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

Cold Work	0.2% Yield Strength		Ultimate Tensile Strength		Elongation
	%	ksi	MPa	ksi	
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 oxyacetylene 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.

Welding Continued

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 Strength		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:

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