HAYNES® HR-224® alloy

Principle Features

HAYNES® HR-224® alloy is a wrought Ni–27.5Fe–20Cr–3.8Al alloy with excellent oxidation resistance and improved fabricability and weldability compared to HAYNES® 214® alloy. This alloy achieves superior oxidation resistance through the formation of a tightly adherent alumina protective scale. It exhibits excellent ductility and formability characteristics, with weldability on par with nickel-iron-chromium alloys of substantially lower aluminum contents. Potential uses include applications in heat recuperators, automotive catalytic converters and heat shields, strand annealing furnace tubulars, fuel cells, gas separation units, applications requiring minimal chromia vaporization, and other severely oxidizing environments.

Nominal Composition

Weight %

Nickel:	47 Balance
Cobalt:	2 max.
Iron:	27.5
Chromium:	20
Molybdenum:	0.5 max.
Tungsten:	0.5 max.
Manganese:	0.5 max.
Silicon:	0.3
Columbium:	0.15 max.
Aluminum:	3.8
Titanium:	0.3
Carbon:	0.05
Boron:	0.004 max.
Zirconium:	0.025 max.

Oxidation Resistance

Comparative Oxidation Resistance in Flowing Air

Material	1600°F (871°C)				1800°F (982°C)			
	Average Metal Loss		Average Metal Affected		Average Metal Loss		Average Metal Affected	
	Mils	µm	Mils	µm	Mils	µm	Mils	µm
HR-224®	**0**	**0**	**0.2**	**5**	**0**	**0**	**0.3**	**8**
214®	0	0	0.3	8	0	0	0.5	13
230®	0	0	0.9	23	0.2	5	1.6	41
625	0.1	3	0.6	15	0.2	5	1.9	48
X	0.1	3	1	25	0.3	8	1.9	48
HR-120®	0.1	3	1.1	28	0.3	8	2.0	51
601	-	-	-	-	0.4	10	1.7	43
800HT	0.1	3	1	25	0.5	13	4.1	104
347SS	0.3	8	0.7	18	-	-	-	-
253MA	0.2	5	0.9	23	1.3	33	3.0	76

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.

Comparative Long-Term Oxidation Resistance

Material	1800°F (982°C)			
	Average Metal Loss		Average Metal Affected	
	Mils	µm	Mils	µm
HR-224®	**0.1**	**3**	**0.1**	**3**
214®	0.1	3	0.5	13
230®	0.1	3	2.7	69
X	0.2	5	2.8	71
HR-120®	0.5	13	3.3	84
625	2.6	66	8.6	218

Alloys exposed for 360 days (8,640 h) in flowing air, cycled once per month.

Comparative Oxidation Resistance in Water Vapor

Material	1400°F (760°C)				1600°F (871°C)			
	Average Metal Loss		Average Metal Affected		Average Metal Loss		Average Metal Affected	
	Mils	µm	Mils	µm	Mils	µm	Mils	µm
HR-224®	**0.05**	**1**	**0.25**	**7**	**0.06**	**2**	**0.26**	**7**
214®	0.02	1	0.22	7	0.05	1	0.35	9
230®	0.09	2	1.19	30	0.21	5	1.91	49
HR-120®	0.12	3	0.72	18	0.26	7	2.06	52

Amount of metal affected for high-temperature sheet (0.125”) alloys exposed for 8640h (cycled monthly) in air + 10%H_2O

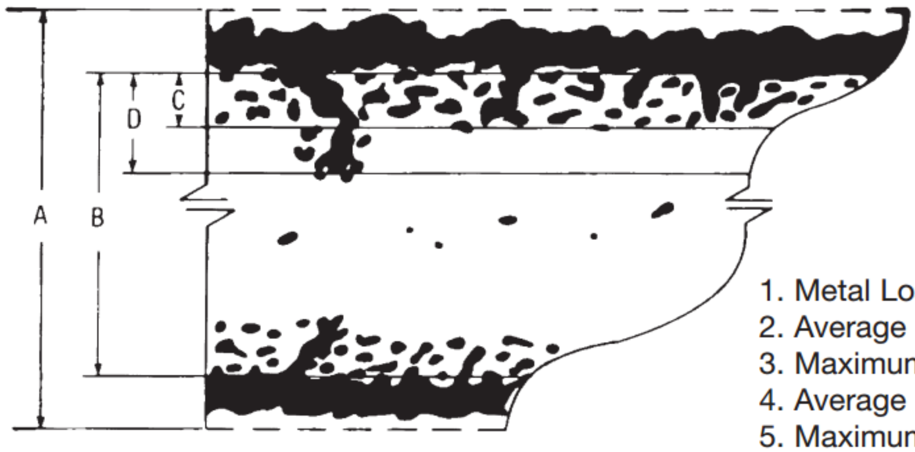
Oxidation Resistance Continued

Comparative Cyclic Oxidation

Material	1400°F (760°C)				1600°F (871°C)				1800°F (982°C)				2000°F (1093°C)			
	Average Metal Loss		Average Metal Affected		Average Metal Loss		Average Metal Affected		Average Metal Loss		Average Metal Affected		Average Metal Loss		Average Metal Affected	
	Mils	µm	Mils	µm	Mils	µm	Mils	µm	Mils	µm	Mils	µm	Mils	µm	Mils	µm
HR-224®	**< 0.1**	**0.6**	**0.1**	**1.9**	**0.1**	**3**	**0.3**	**8**	**0.1**	**3**	**0.3**	**8**	**0.2**	**5**	**0.8**	**20**
214®	< 0.1	0.3	0.1	1.6	0.1	3	0.1	3	0.1	3	0.5	13	0.1	6	0.4	10
230®	< 0.1	0.8	0.1	2.7	0.1	3	0.7	18	0.2	5	1.1	28	0.9	23	4.1	104
X	-	-	-	-	0.2	5	1.0	25	0.3	8	1.6	41	10	254	12.1	307
601	-	-	-	-	-	-	-	-	0.5	13	1.9	48	-	-	-	-
625	-	-	-	-	0.1	3	0.5	13	0.4	10	2.0	51	-	-	-	-
HR-120®	< 0.1	1.2	0.2	6.0	0.2	5	0.9	23	0.4	10	2.0	51	18.5	470	20.6	523
600	-	-	-	-	0.1	3	0.8	20	0.5	13	2.2	56	-	-	-	-
800HT	-	-	-	-	0.3	8	1.3	33	8	203	9.8	249	30.8	782	32.2	818

Amount of metal affected for alloys exposed to flowing air for 1000-h, cycled 1x/10h

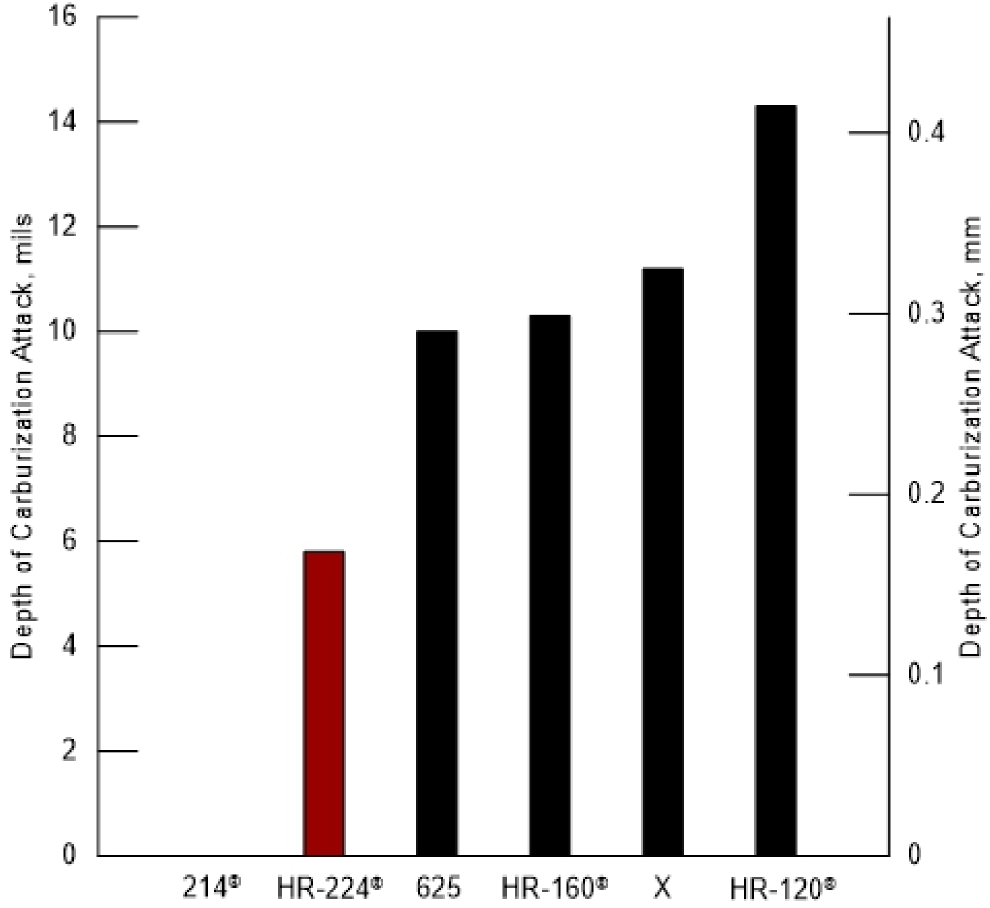
Schematic Representation of Metallographic Technique used for Evaluating Oxidation



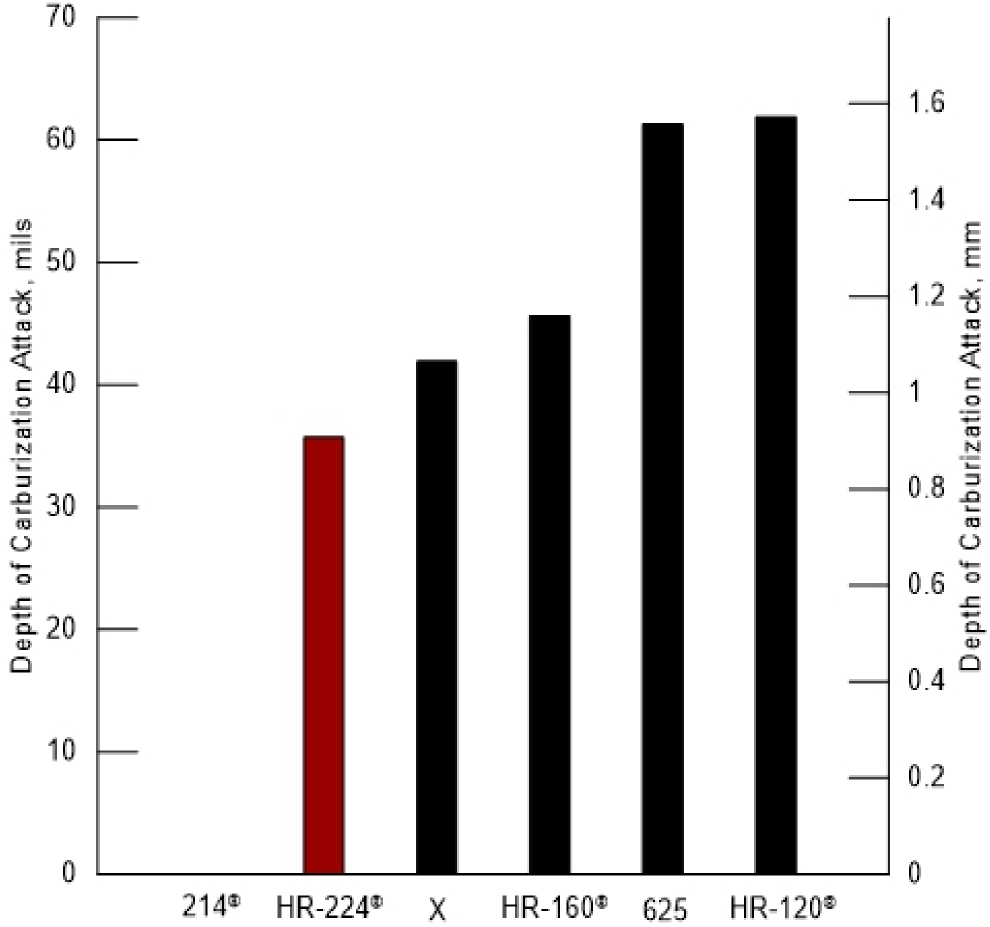
1. Metal Loss = (A - B)/2
2. Average Internal Penetration = C
3. Maximum Internal Penetration = D
4. Average Metal Affected = ((A - B)/2) + C
5. Maximum Metal Affected = (A - B)/2) + D

Carburization Resistance

Depth of Carburization Attack in Ar-5%H_2-2%C_3H_6 at 1600°F (871°C) for 124 hours



Depth of Carburization Attack in Ar-5%H_2-2%C_3H_6 at 2000°F (1093°C) for 24 hours



Carburization Resistance Continued

Laboratory Carburization Testing in Ar-5%H_2-2%C_3H_6 at 2000°F (1093°C) for 24 hours

Alloy	Carbon Absorption	Total Depth of Attack	
	(mg/cm²)	mil	mm
214®	0.2	0	0
HR-224®	**3.7**	**35.7**	**0.9**
HR-160®	7.1	45.6	1.2
625	8.9	> 61.3	> 1.6
X	11.7	41.9	1.1
HR-120®	13.6	> 61.9	> 1.6

Note: Preliminary data from a single test. 625 and HR-120 exhibited through-thickness carburization attack.

Laboratory Carburization Testing in Ar-5%H_2-2%C_3H_6 at 1600°F (871°C) for 124 hours

Alloy	Carbon Absorption	Total Depth of Attack	
	(mg/cm²)	mil	mm
214®	0.4	0	0
HR-160®	0.9	10.3	0.26
HR-224®	**1.4**	**5.8**	**0.15**
625	2.6	10.0	0.25
X	3.6	11.2	0.28
HR-120®	4.0	14.3	0.36

Note: Preliminary data from a single test.

Thermal Stability

Room Temperature Properties after Exposure

Exposure Temperature		Time	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	h	ksi	MPa	ksi	MPa	%
As-Annealed	As-Annealed	0	46	318	108	745	50
1200	649	4000	102	703	153	1055	21
		8000	103	709	148	1020	12
		16000	102	703	144	992	10
1400	760	4000	61	420	130	896	25
		8000	58	402	127	879	20
		16000	55	379	123	848	21
1600	871	4000	39	269	104	717	39
		8000	40	276	104	717	40
		16000	38	262	104	717	41
1800	982	4000	44	303	100	690	46
		8000	44	303	93	639	43
		16000	42	290	94	648	50

Creep-Rupture Strength

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in							
			10 hours		100 hours		1000 hours		10,000 hours	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	0.1	36.9	254	26.8	185	19.6	135	14.5	100
		1.0	59.7	412	39.1	270	26.1	180	17.7	122
		R	82.8	571	18.3	126	29.1	201	18.0	124
1300	704	0.1	19.1	132	13.9	96	10.2	70	7.6	52
		1.0	29.0	200	19.2	132	12.9	89	8.9	61
		R	43.4	299	25.5	176	15.5	107	9.7	67
1400	760	0.1	10.3	71	7.5	52	5.6	39	4.2	29
		1.0	14.9	103	9.9	68	6.8	47	4.8	33
		R	23.7	163	14.1	97	8.7	60	5.5	38
1500	816	0.1	5.8	40	4.3	30	3.2	22	2.4	17
		1.0	8.1	56	5.5	38	3.8	26	2.7	19
		R	13.5	93	8.1	56	5.1	35	3.3	23
1600	871	0.1	3.4	23	2.5	17	1.9	13	1.5	10
		1.0	4.6	32	3.2	22	2.3	16	1.7	12
		R	8.0	55	4.9	34	3.2	22	2.1	14
1700	927	0.1	2.1	14	1.6	11	1.2	8	0.9	6
		1.0	2.8	19	2.0	14	1.4	10	1.1	8
		R	5.0	34	3.1	21	2.1	14	1.4	10
1800	982	0.1	1.3	9	1.0	7	0.8	6	0.6	4
		1.0	1.8	12	1.3	9	1.0	7	0.8	6
		R	3.2	22	2.1	14	1.4	10	1.0	7
1900	1038	0.1	0.9	6	0.7	5	0.5	3	0.4	3
		1.0	1.2	8	0.9	6	0.7	5	0.6	4
		R	2.2	15	1.4	10	1.0	7	0.8	6
2000	1093	0.1	0.6	4	0.5	3	0.4	3	0.3	2
		1.0	0.8	6	0.7	5	0.5	3	0.4	3
		R	1.5	10	1.1	8	0.8	6	0.6	4

R = Rupture

Resistance to Strain-Age Cracking

The Controlled Heating-Rate Tensile (CHRT) test is an excellent measure of the resistance of gamma-prime forming superalloys to strain-age cracking. Samples of thickness 0.063" (1.6 mm), originally in the solution annealed condition, are heated to the test temperature at a rate of 25-30°F (14-17°C) per minute, this being representative of a typical post-weld heat treatment. In this case, tests were performed at 1450°F (788°C). The susceptibility to strain-age cracking is related to the minimum tensile elongation observed within that temperature range (the higher the minimum elongation, the greater is the resistance to strain-age cracking).

HAYNES® HR-224® Strain-Age Cracking Resistance

Alloy	CHRT Elongation (%)*
HAYNES® HR-224®	**16****
HAYNES® 214®	12
HAYNES® 282®	16
HAYNES® 718	15
HAYNES® R-41	7

*Average of three tests.
**Average of two heats
Controlled Heating Rate Test - 100°F/sec to 1100°F - 30°F/minute to 1450°F - Hold 1450°F and pull to failure at 0.0625 inches/minute.

Metzler, D.A. 2008. A Gleeble®-based Method for Ranking the Strain-Age Cracking Susceptibility of Ni-Based Superalloys, Welding Journal 87(10): 249-s to 256-s.

Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.280 lb/in³	RT	7.72 g/cm³
Melting Temperature	2450-2510°F	-	1340-1380°C	-
Electrical Resistivity	RT	48.6 µohm-in	RT	123.5 µohm-cm
	200°F	49.0 µohm-in	100°C	125.2 µohm-cm
	400°F	50.2 µohm-in	200°C	127.5 µohm-cm
	600°F	51.1 µohm-in	300°C	130.0 µohm-cm
	800°F	52.0 µohm-in	400°C	131.7 µohm-cm
	1000°F	52.6 µohm-in	500°C	133.5 µohm-cm
	1200°F	52.8 µohm-in	600°C	134.0 µohm-cm
	1400°F	52.9 µohm-in	700°C	134.2 µohm-cm
	1600°F	53.0 µohm-in	800°C	134.5 µohm-cm
	1700°F	53.0 µohm-in	900°C	134.4 µohm-cm
	-	-	1000°C	135.4 µohm-cm
Thermal Diffusivity	RT	4.3×10^{-3} in²/sec	RT	27.5×10^{-3} cm²/s
	200°F	4.5×10^{-3} in²/sec	100°C	29.5×10^{-3} cm²/s
	400°F	5.0×10^{-3} in²/sec	200°C	32.1×10^{-3} cm²/s
	600°F	5.4×10^{-3} in²/sec	300°C	34.5×10^{-3} cm²/s
	800°F	5.8×10^{-3} in²/sec	400°C	37.2×10^{-3} cm²/s
	1000°F	6.3×10^{-3} in²/sec	500°C	39.4×10^{-3} cm²/s
	1200°F	6.7×10^{-3} in²/sec	600°C	42.0×10^{-3} cm²/s
	1400°F	7.0×10^{-3} in²/sec	700°C	44.7×10^{-3} cm²/s
	1600°F	7.0×10^{-3} in²/sec	800°C	44.9×10^{-3} cm²/s
	1700°F	7.1×10^{-3} in²/sec	900°C	45.0×10^{-3} cm²/s
	-	-	1000°C	47.4×10^{-3} cm²/s
Thermal Conductivity	RT	69 Btu-in/ft²-hr-°F	RT	10.0 W/m-°C
	200°F	74 Btu-in/ft²-hr-°F	100°C	11.2 W/m-°C
	400°F	89 Btu-in/ft²-hr-°F	200°C	12.7 W/m-°C
	600°F	100 Btu-in/ft²-hr-°F	300°C	14.2 W/m-°C
	800°F	112 Btu-in/ft²-hr-°F	400°C	15.7 W/m-°C
	1000°F	123 Btu-in/ft²-hr-°F	500°C	17.1 W/m-°C
	1200°F	135 Btu-in/ft²-hr-°F	600°C	18.7 W/m-°C
	1400°F	142 Btu-in/ft²-hr-°F	700°C	20.3 W/m-°C
	1600°F	149 Btu-in/ft²-hr-°F	800°C	20.7 W/m-°C
	1700°F	149 Btu-in/ft²-hr-°F	900°C	21.1 W/m-°C
	-	-	1000°C	22.6 W/m-°C

Physical Properties Continued

Physical Property	British Units		Metric Units	
Specific Heat	RT	0.112 Btu/lb-°F	RT	471 J/kg·°C
	200°F	0.117 Btu/lb-°F	100°C	492 J/kg·°C
	400°F	0.123 Btu/lb-°F	200°C	514 J/kg·°C
	600°F	0.128 Btu/lb-°F	300°C	532 J/kg·°C
	800°F	0.132 Btu/lb-°F	400°C	548 J/kg·°C
	1000°F	0.136 Btu/lb-°F	500°C	564 J/kg·°C
	1200°F	0.139 Btu/lb-°F	600°C	577 J/kg·°C
	1400°F	0.142 Btu/lb-°F	700°C	588 J/kg·°C
	1600°F	0.145 Btu/lb-°F	800°C	600 J/kg·°C
	1700°F	0.146 Btu/lb-°F	900°C	608 J/kg·°C
	-	-	1000°C	616 J/kg·°C
Mean Coefficient of Thermal Expansion	70-200°F	7.8 μin/in -°F	25-100°C	14.0 x 10^{-6}m/m·°C
	70-400°F	8.1 μin/in -°F	25-200°C	14.5 x 10^{-6}m/m·°C
	70-600°F	8.2 μin/in -°F	25-300°C	14.8 x 10^{-6}m/m·°C
	70-800°F	8.3 μin/in -°F	25-400°C	14.9 x 10^{-6}m/m·°C
	70-1000°F	8.3 μin/in -°F	25-500°C	14.9 x 10^{-6}m/m·°C
	70-1200°F	8.3 μin/in -°F	25-600°C	14.8 x 10^{-6}m/m·°C
	70-1400°F	8.9 μin/in -°F	25-700°C	15.3 x 10^{-6}m/m·°C
	70-1600°F	9.4 μin/in -°F	25-800°C	16.5 x 10^{-6}m/m·°C
	70-1700°F	9.7 μin/in -°F	25-900°C	17.2 x 10^{-6}m/m·°C
	-	-	25-1000°C	18.2 x 10^{-6}m/m·°C
Dynamic Modulus of Elasticity	RT	28.5 x 10^6 psi	RT	197 GPa
	200°F	27.5 x 10^6 psi	100°C	191 GPa
	400°F	27.0 x 10^6 psi	200°C	186 GPa
	600°F	26.2 x 10^6 psi	300°C	181 GPa
	800°F	25.3 x 10^6 psi	400°C	176 GPa
	1000°F	24.5 x 10^6 psi	500°C	170 GPa
	1200°F	23.5 x 10^6 psi	600°C	164 GPa
	1400°F	22.0 x 10^6 psi	700°C	158 GPa
	1600°F	21.3 x 10^6 psi	800°C	152 GPa
	1800°F	20.2 x 10^6 psi	900°C	146 GPa
	-	-	1000°C	139 GPa

Tensile Properties

HAYNES® HR-224® Tensile Properties - Sheet

Test Temperature		Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	47.6	328	106.1	732	47
1000	538	42.7	295	95.3	657	57
1200	649	56.2	387	84.3	581	16
1400	760	57.9	399	68.5	472	14
1600	871	14.3	99	18.3	126	102
1800	982	6.9	48	9.2	64	105

HAYNES® HR-224® Tensile Properties - Plate

Test Temperature		Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	45.9	316	105.6	728	49
1000	538	42.2	291	93.6	645	57
1200	649	55.2	381	78.6	542	14
1400	760	59.5	410	69.6	480	9
1600	871	15.6	108	21.7	150	105
1800	982	5.8	40	9.5	66	125

HAYNES® HR-224® Tensile Properties - Bar

Test Temperature		Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	45.8	316	106.5	734	48	72
1000	538	43.0	296	93.4	644	53	61
1200	649	54.8	378	74.5	514	13	22
1400	760	57.5	396	69.6	480	11	12
1600	871	12.9	89	19.5	135	106	93
1800	982	6.3	43	9.8	67	101	95

Annealing Response After Cold Forming

Effect of Cold Reduction on Room Temperature Tensile Properties*

Cold Reduction	Subsequent Anneal Temperature	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Hardness
%	-	ksi	MPa	ksi	MPa	%	Rb
0	-	51	352	107	738	47	87
10	1900°F (1038°C) for 5 min	51.9	358	100.7	694	45.6	86
20		58.3	402	103.9	716	43.1	85
30		55.5	383	106.1	732	41.2	88
40		45.4	313	105.2	725	45.4	90
50		48.6	335	110.2	760	45	90
10	2000°F (1093°C) for 5 min	48.2	332	97.3	671	48.5	90
20		51	352	98.4	678	47.5	89
30		41.7	288	100.9	696	47.8	88
40		42.8	295	103.6	714	47.1	86
50		46.2	319	107.4	741	44.2	91

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

Heat Treatment

HAYNES® HR-224® alloy is furnished in the solution heat-treated condition, unless otherwise specified. The alloy is normally final solution heat-treated at 2025 to 2075°F (1107 to 1135°C) for a time commensurate with section thickness and rapidly cooled or water-quenched for optimal properties.