HAYNES® R-41 alloy

Principle Features

Vacuum-melted, nickel-based HAYNES® R-41 (UNS N07041) alloy has exceptionally high strength at temperatures in the range of 1200 to 1800°F (649 to 982°C). The alloy is a precipitation-hardening type and strength is developed by various solution annealing and aging heat treatments. Because of its high strength and good oxidation resistance, the alloy is being used in afterburner parts and nozzle diaphragm partitions in current gas turbine engines. In the annealed condition, the alloy is ductile and has essentially the same forming characteristics as 18-8 stainless steel and other nickel-based alloys. It is stronger, however, and has a greater resistance to forming. The alloy has been formed with success on drop hammers, expanding mandrels and stretch formers. R-41 alloy is now being replaced in many applications by HAYNES® 282® alloy, due to the superior fabricability of 282® alloy.

Mechanical properties can be tailored by selecting various combinations of solution annealing and aging treatments. In general, higher solution heat treating temperatures result in better room-temperature ductility and improved formability. Stress-rupture strength is also improved by this type of treatment. Lower solution annealing temperatures produce higher tensile strengths at temperatures up to about 1700°F (927°C). The effect of solution heat treating temperature can be seen in tensile and stress-rupture data.

Nominal Composition

Weight %

Nickel:	52 Balance
Chromium:	19
Cobalt:	11
Iron:	5 max.
Molybdenum:	10
Titanium:	3.1
Aluminum:	1.5
Silicon:	0.5 max.
Manganese:	0.1 max.
Carbon:	0.09
Boron:	0.006
Zirconium:	0.07 max.

Physical Properties

Physical Property	Bristish Units		Metric Units	
Density	70°F	0.298 lb/in³	21°C	8.25 g/cm³
Melting Temperature	2250-2535°F	-	1232-1391°C	-
Mean Coefficient of Thermal Expansion	70-1000°F	7.5 µin/in -°F	21-538°C	13.5 x 10^{-6}m/m·°C
	70-1200°F	7.8 µin/in -°F	21-649°C	14.0 x 10^{-6}m/m·°C
	70-1400°F	8.2 µin/in -°F	25-760°C	14.8 x 10^{-6}m/m·°C
	70-1500°F	8.5 µin/in -°F	25-816°C	15.2 x 10^{-6}m/m·°C
	70-1600°F	8.8 µin/in -°F	25-871°C	15.7 x 10^{-6}m/m·°C
	70-1700°F	9.1 µin/in -°F	25-927°C	16.3 x 10^{-6}m/m·°C
	70-1800°F	9.4 µin/in -°F	25-982°C	16.8 x 10-6m/m·°C
Thermal Conductivity	300°F	80 Btu-in/ft²-hr-°F	149°C	11.5 W/m-°C
	400°F	87 Btu-in/ft²-hr-°F	204°C	12.5 W/m-°C
	500°F	95 Btu-in/ft²-hr-°F	260°C	13.6 W/m-°C
	600°F	102 Btu-in/ft²-hr-°F	316°C	14.7 W/m-°C
	800°F	117 Btu-in/ft²-hr-°F	427°C	16.8 W/m-°C
	1000°F	131 Btu-in/ft²-hr-°F	538°C	18.8 W/m-°C
	1100°F	139 Btu-in/ft²-hr-°F	593°C	20.0 W/m-°C
	1200°F	146 Btu-in/ft²-hr-°F	649°C	21.0 W/m-°C
	1300°F	153 Btu-in/ft²-hr-°F	704°C	22.0 W/m-°C
	1400°F	161 Btu-in/ft²-hr-°F	760°C	23.1 W/m-°C
	1500°F	168 Btu-in/ft²-hr-°F	816°C	24.1 W/m-°C
	1600°F	175 Btu-in/ft²-hr-°F	871°C	25.1 W/m-°C
Specific Heat	70°F	0.108 Btu/lb.-°F	21°C	452 J/kg-°C
Electrical Resistivity	32°F	50.0 µohm-in	0°C	127.0 µohm-cm
Magnetic Permeability	70°F	<1.002 at 200 oersteds	21°C	<1.002 at 200 oersteds

Tensile Data

Tensile properties after heat treating at 2050°F (1121°C) /30 min./RAC + 1650°F (899°C) /4h/AC

Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		4D Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	116.4	803	181.8	1253	20.5
400	204	109*	752*	174.2*	1201*	16.5*
800	427	109.1*	752*	161.6*	1114*	20.3*
1000	538	107.2	739	161	1110	21.2
1200	649	107.7	743	172.9	1192	19.3
1400	760	114.3	788	139.1	959	28.3
1500	816	104*	717*	115.7*	798*	27.2*
1600	871	79.7	550	89.2	615	28.5
1700	927	59.1*	407*	66.9*	461*	24.8*
1800	982	34.2	236	40.2	277	31.1
2000	1093	4.9*	34*	8.5*	59*	94.4*

*Limited data

Tensile properties after heat treating at 1400°F (760°C) /16h/AC

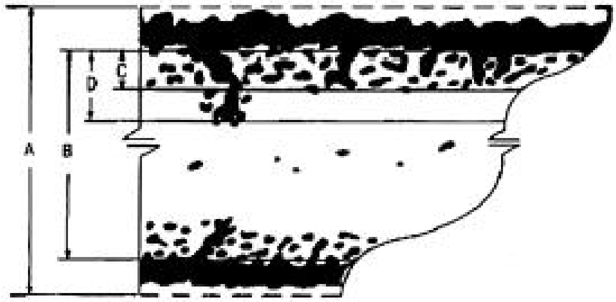
Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		4D Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	154.3	1064	205.4	1416	22.3
400	204	141.2*	974*	198.2*	1367*	23.0*
800	427	141.8*	978*	181.6*	1252*	25.6*
1000	538	139.8	964	182.6	1259	20.5
1200	649	138.3	954	196.2	1353	23.4
1400	760	126.1	869	150.8	1040	17.9
1500	816	112.2	774	128.1	883	19.4
1600	871	83.9	578	98.5	679	31.4
1700	927	51.1	352	62.3	430	38.7
1800	982	25.9	179	34.5	238	42.7

*Limited data

Oxidation Resistance

Static Oxidation Testing

Environment: Flowing Air
Test Duration: 1,008 h
Number of Cycles: 6
Cycle Length: 168 h
Temperatures: 1600, 1700, 1800°F (871, 927, 982°C)
Metal Loss = (A-B)/2
Average Internal Penetration = C
Maximum Internal Penetration = D
Average Metal Affected = Metal Loss + Average Internal Penetration
Maximum Metal Affected = Metal Loss + Maximum Internal Penetration



Comparative Oxidation Resistance in Flowing Air, 1008 Hours

	1600°F (871°C)				1700°F (927°C)				1800°F (982°C)			
	Metal Loss, mils (µm)		Avg. Met. Aff. mils, (µm)		Metal Loss, mils (µm)		Avg. Met. Aff. mils, (µm)		Metal Loss, mils (µm)		Avg. Met. Aff. mils, (µm)	
Alloy	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**
263	0.1	3	0.4	10	0.2	5	0.7	18	0.9	23	5.0	127
282®	**0.2**	**5**	**0.6**	**15**	**0.1**	**3**	**1.1**	**28**	**0.2**	**5**	**1.8**	**46**
R-41	0.2	5	0.8	20	0.2	5	1.5	38	0.2	5	2.9	74
Waspaloy	0.3	8	1.4	36	0.3	8	3.4	86	0.7	18	5.0	127

Dynamic Oxidation Testing (Burner Rig)

Burner rig oxidation tests were conducted by exposing, in a rotating holder, samples 0.375 inch x 2.5 inches x thickness (9.5mm x 64mm x thickness) to the products of combustion of fuel oil (2 parts No. 1 and 1 part No. 2), burned at an air to fuel ratio of about 50:1. The gas velocity was about 0.3 mach. Samples were automatically removed from the gas stream every 30 minutes and fan cooled to less than 500°F (260°C) and then reinserted into the flame tunnel.

	1600°F (871°C), 1000 hours, 30 minute cycles				1800°F (982°C), 1000 hours, 30 minute cycles			
	Metal Loss, mils (µm)		Avg. Met. Aff. mils, (µm)		Metal Loss, mils (µm)		Avg. Met. Aff. mils, (µm)	
Alloy	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**
263	1.4	36	4.0	102	12.5	318	16.1	409
282®	**1.8**	**46**	**4.2**	**107**	**8.0**	**203**	**13.0**	**330**
Waspaloy	1.9	48	4.3	109	9.5	241	13.6	345
R-41	1.2	30	4.4	112	5.8	147	12.1	307

Aged Hardness

Age Hardened Room Temperature Hardness

Form	Hardness	Heat Treatment
Sheet	35 HRC	2050F, 30 Min, AC + 1650F, 4 Hr, AC
Plate	36 HRC	2050F, 30 Min, AC + 1650F, 4 Hr, AC
Sheet	42 HRC	1400F, 16 Hr, AC
Plate	39 HRC	1400F, 16 Hr, AC

HRC = Hardness Rockwell "C"

Creep-Rupture

HAYNES® R-41 Sheet, Age-Hardened*

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in			
			100h		1,000h	
°F	°C	%	ksi	MPa	ksi	MPa
1200	649	1	105	724	84	579
		R	110	758	90	621
1300	704	1	75	517	59	407
		R	85	586	68	469
1400	760	1	53	365	34	234
		R	63	434	43	296
1500	816	1	32	221	18	124
		R	39	269	24	165
1600	871	1	17	117	9.0	62
		R	23	159	13	90
1700	927	1	8.4	58	4.6	32
		R	13	90	6.5	45

*Samples were age hardened by heat treating at 2050°F (1121°C) /30 min./RAC + 1650°F (899°C) /4h/AC

Thermal Stability

Baseline Tensile Properties at RT and ET; Residual Tensile Properties at Room Temperature and Exposure Temperature

Condition	Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		4D Elongation
	°F	°C	ksi	MPa	ksi	MPa	%
Solution Annealed	RT	RT	83.6	576	151.4	1044	38.7
Age Hardened*	RT	RT	116.8	805	178.6	1231	17.3
	1200	649	103.1	711	169.6	1169	18.0
	1400	760	111.6	769	138.2	953	28.4
	1500	816	100.6	694	113.5	783	32.0
	1600	871	78.1	538	87.9	606	30.0
Age Hardened* + 1200°F/8000h	RT	RT	150.7	1039	188.5	1300	5.3
	1200	649	129.7**	894**	182.6	1259	8.1**
Age Hardened* + 1400°F/8000h	RT	RT	151.6**	1045**	173.9**	1199**	0.1
	1400	760	88.2	608	126.8	874	30.1**
Age Hardened* + 1500°F/8000h	RT	RT	113.5	783	156.6	1080	1.4
	1500	816	58.2	401	88.5	610	26.8
Age Hardened* + 1600°F/8000h	RT	RT	83.3	574	122.9	847	2.0
	1600	871	36.3	250	60.9	420	33.0

*Aged hardened at 2050°F (1121°C)/30 MAT/AC + 1650°F (899°C)/4H/AC
**Limited data

Elastic Modulus

Elastic Modulus, Share Modulus, and Poisson's Ratio

Test Temperature		Modulus of Elasticity		Shear Modulus		Poisson's Ratio
°F	°C	10^6 psi	GPa	10^6 psi	GPa	
80	27	31.6	218	12	83	0.31
300	149	30.9	213	12	81	0.31
500	260	29.6	204	11	77	0.32
700	371	28.7	198	11	75	0.32
900	482	27.6	190	10	72	0.32
1000	538	27.2	188	-	-	-
1100	593	26.4	182	10	69	0.33
1200	649	25.9	179	-	-	-
1250	677	25.8	178	10	67	0.33
1400	760	24.8	171	9	64	0.33
1500	816	24.1	166	-	-	-
1550	843	23.7	163	9	61	0.34
1600	871	23.2	160	-	-	-
1700	927	21.8	150	8	55	0.35

Heat Treatment

Wrought HAYNES® R-41 alloy is furnished in the solution annealed condition unless otherwise specified. After component fabrication, the alloy would normally again be solution annealed at 1950°F - 2150°F (1066°C - 1177°C) for a time commensurate with section thickness and rapidly cooled or water-quenched for optimal properties. Following solution annealing, the alloy is given an age-hardening treatment to optimize the microstructure and induce age-hardening. A variety of age hardening practices are used commercially, all of which include heat treating in the range of 1400°F - 1800°F (760°C - 982°C). For example, AMS 5545 specifies age hardening samples at 1400°F (760°C) for a minimum of 16 hours and air cooling.

Fabrication

Solution Annealed Room Temperature Hardness

Form	Hardness	Typical ASTM Grain Size
Sheet	98 HRB	5 - 7.5
Plate	31 HRC	4 - 6

All samples tested in solution-annealed condition

R-41, Solution Annealed, Room Temperature Tensile

Form	Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		4D Elongation
	°F	°C	ksi	MPa	ksi	MPa	%
Sheet	RT	RT	84.2	581	148.1	1021	44.7
Plate	RT	RT	101.0	696	195.0	1344	38.8

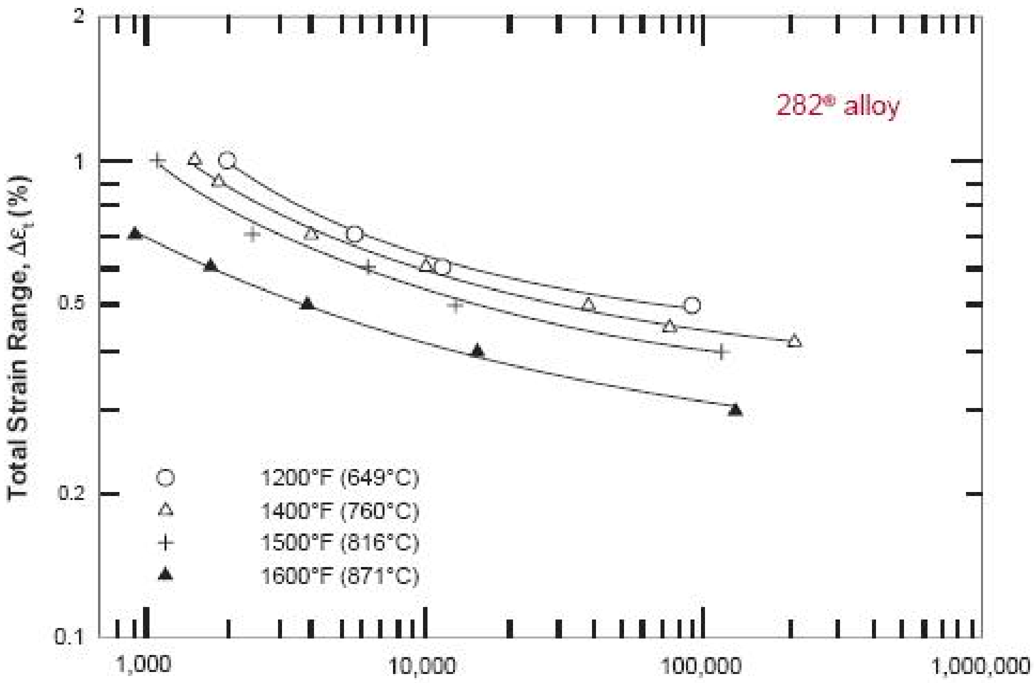
For welding HAYNES® R-41 alloy, please review the General Welding and Joining Guidelines. In addition to those guidelines, there are some additional considerations when welding R-41 alloy.

HAYNES® R-41 alloy is a precipitation-strengthened alloy and requires a postweld heat treatment (PWHT) to develop suitable properties. Postweld heat treatment for R-41 alloy consists of two parts: a solution anneal, which is followed by a suitable aging treatment. Details can be found in the Heat Treatment section. During PWHT, the gamma-prime phase (Ni3Al,Ti) precipitates and the alloy undergoes a slight volumetric contraction. This makes it susceptible to strain-age cracking, which typically occurs upon heating to the solution annealing temperature. To inhibit strain-age cracking, the heating rate to the solution annealing temperature should be as fast as possible, within the capability of the furnace being used.

Filler metal of matching composition is suggested for welding R-41 alloy to itself. For filler metal suggestions for welding R-41 alloy to other alloys, please refer to the Haynes Welding SmartGuide, or contact Haynes International for further guidance.

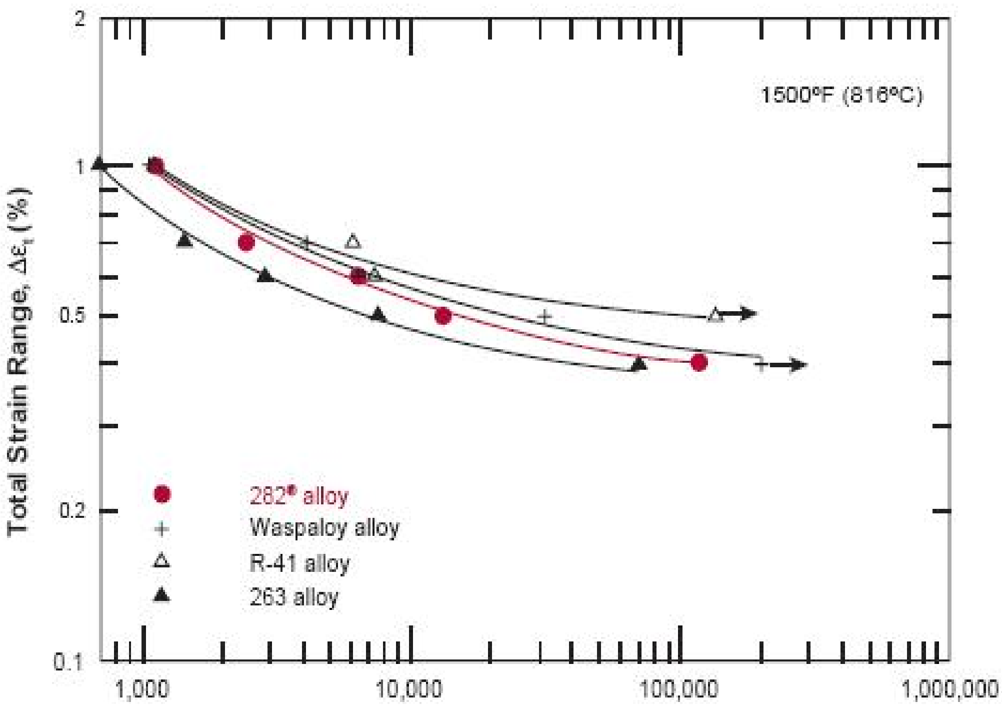
Low Cycle Fatigue

Low-Cycle Fatigue Data – HAYNES® 282® Sheet* (Thickness 0.125", 3.2 mm)
*Age-hardened at 1850ºF(1010ºC)/2h/AC + 1450ºF(788ºC)/8h/AC



Fully Reversed, R = -1, Waveform = Triangle, Frequency = 0.33Hz

Comparative Low-Cycle Fatigue Data



1500°F (816°C), Fully Reversed, R = -1, Waveform = Triangle, Frequency = 0.33Hz, Material: 0.125"(3.2 mm) Sheet*

Specifications and Codes

Specifications

HAYNES® R-41 alloy (N07041)	
Sheet, Plate & Strip	AMS 5545
Billet, Rod & Bar	AMS 5712
Coated Electrodes	-
Bare Welding Rods & Wire	AMS 5800
Seamless Pipe & Tube	-
Welded Pipe & Tube	-
Fittings	-
Forgings	AMS 5712
DIN	-
Others	-

Codes

HAYNES® R-41 (N07041)	
MMPDS	6.3.7