

HAYNES® 214® alloy

Principle Features

Excellent Oxidation Resistance

HAYNES® 214® alloy (UNS N07214) is a nickel - chromium-aluminum-iron alloy, designed to provide the optimum in high-temperature oxidation resistance for a wrought austenitic material, while at the same time allowing for conventional forming and joining. Intended principally for use at temperatures of 1750°F (955°C) and above, 214® alloy exhibits resistance to oxidation that far exceeds virtually all conventional heat-resistant wrought alloys at these temperatures. This is attributable to the formation of a tightly adherent Al_2O_3 -type protective oxide scale, which forms in preference to chromium oxide scales at these high temperatures. At temperatures below 1750°F (955°C), 214® alloy develops an oxide scale which is a mixture of chromium and aluminum oxides. This mixed scale is somewhat less protective, but still affords 214® alloy oxidation resistance equal to the best nickel-base alloys. The higher temperature Al_2O_3 - type scale which 214® alloy forms also provides the alloy with excellent resistance to carburization, nitriding and corrosion in chlorine-bearing oxidizing environments.

Fabrication

HAYNES® 214® alloy, like many high aluminum content nickel-base alloys that are intended to be age-hardened by intermediate temperature heat treatment, will exhibit age-hardening as a result of the formation of a second phase, gamma prime (Ni_3Al), if exposed at temperatures in the range of 1100 - 1700°F (595 - 925°C). As a consequence of this, 214® alloy is susceptible to strain-age cracking when highly stressed, highly-restrained, welded components are slowly heated through the intermediate temperature regime. The keys to avoiding this problem are to minimize weldment restraint through appropriate component design, and/or heat rapidly through the 1100 - 1700°F (595 - 925°C) temperature range during post-fabrication heat treatment (or first-use heat-up).

With the exception of the above consideration, HAYNES® 214® alloy does exhibit good forming and welding characteristics. It may be forged or otherwise hot-worked, providing it is held at 2100°F (1150°C) for a time sufficient to bring the entire piece to temperature. Its room temperature tensile ductility is also high enough to allow the alloy to be formed by cold working. All cold or hot-worked 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 (TIG), gas metal arc (MIG) or shielded metal arc (coated electrode) welding.

Heat-Treatment

HAYNES® 214® alloy is furnished in the solution heat-treated condition, unless otherwise specified. The alloy is normally solution heat-treated at 2000°F (1095°C) and rapidly cooled or quenched for optimum properties. Heat treating at temperatures below the solution heat-treating temperature will result in grain boundary carbide precipitation and, below 1750°F (955°C), precipitation of gamma prime phase. Such lower temperature age-hardening heat treatments are not suggested.

Principle Features Continued

Applications

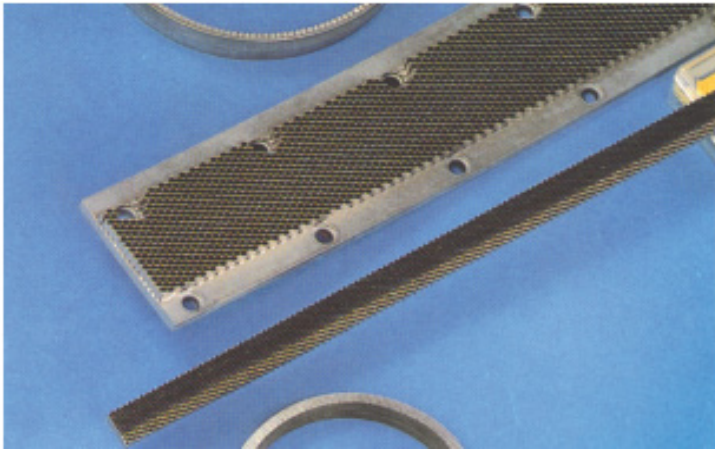
HAYNES® 214® alloy combines properties which make it very suitable for service in relatively low-stress, high temperature oxidizing environments, where the utmost in resistance to oxidation or scale exfoliation is needed. Its resistance to such environments persists to temperatures as high as 2400°F (1315°C), although strength limitations may apply. Applications can include “Clean Firing” uses such as mesh belts, trays and fixtures for firing of pottery and fine china, and the heat treatment of electronic devices and technical grade ceramics. In the gas turbine industry, 214® alloy is used for foil construction honeycomb seals, combustor splash plates, and other static oxidation - limited parts. The automotive industry has applications for 214® alloy in catalytic converter internals, and it is used as a burner cup material in auxiliary heaters for military vehicles. In the industrial heating market, 214® alloy is used for highly specialized applications such as refractory anchors, furnace flame hoods, and rotary calciners for processing chloride compounds. It is also used for parts in high temperature chlorine-contaminated environments, such as hospital waste incinerator internals.

Nominal Composition

Weight %

Nickel:	75 Balance
Chromium:	16
Aluminum:	4.5
Iron:	3
Cobalt:	2 max.
Manganese:	0.5 max.
Molybdenum:	0.5 max.
Titanium:	0.5 max.
Tungsten:	0.5 max.
Niobium:	0.15 max.
Silicon:	0.2 max.
Zirconium:	0.1 max.
Carbon:	0.04
Boron:	0.01 max.
Yttrium:	0.01

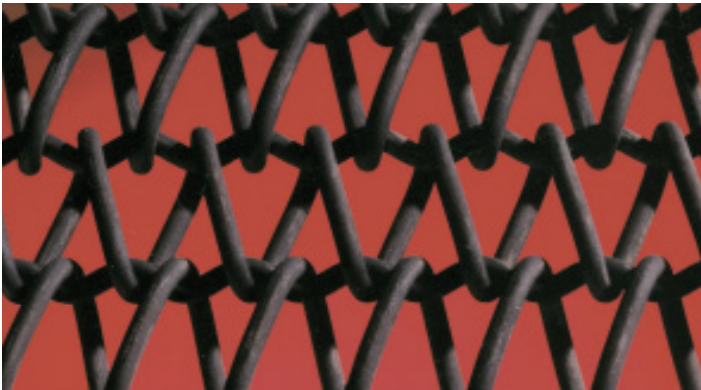
Typical Applications



HAYNES® 214® alloy is gaining rapid acceptance for use in honeycomb seals because of its outstanding oxidation resistance. The seals are made of thin gage foil and are used to prevent leakage between different stages in gas turbine engines. Such seals contribute to an engine's fuel efficiency.



This 214® alloy flamehood remained in service for 16 months in an application where other nickel alloy hoods required replacement every three to four months. The alloy component was subjected to direct flame impingement during the entire period in an automotive products plant.



Section of a 214® alloy belt which was removed after 3,000 hours at 1800°F (980°C) in a chinaware decorating kiln. The belt showed only minimal wear and oxidation attack. Use of 214® alloy in this application has helped reduce the time of the operation from eight or twelve hours, to less than 30 minutes.



The burner assembly at left failed after 450 cycles between minus 55 and 2000°F (minus 50 and 1095°C.) A 214® alloy burner was still in good shape after 2000 cycles in the same test. The burners were cycled from low to high temperatures in about five minutes, held for a 15-minute burn, and then rapid-air cooled.

Oxidation Resistance

HAYNES® 214® alloy provides resistance to oxidation at temperatures of 1750°F (955°C) and above that is virtually unmatched by any other wrought heat-resistant alloy. It can be used for long-term continuous exposure to combustion gases or air at temperatures up to 2300°F (1260°C), and, for shorter term exposures, it can be used at even higher temperatures. Useful short-term oxidation resistance has even been demonstrated at temperatures as high as 2400°F (1315°C).

Comparative Oxidation Resistance in Flowing Air*

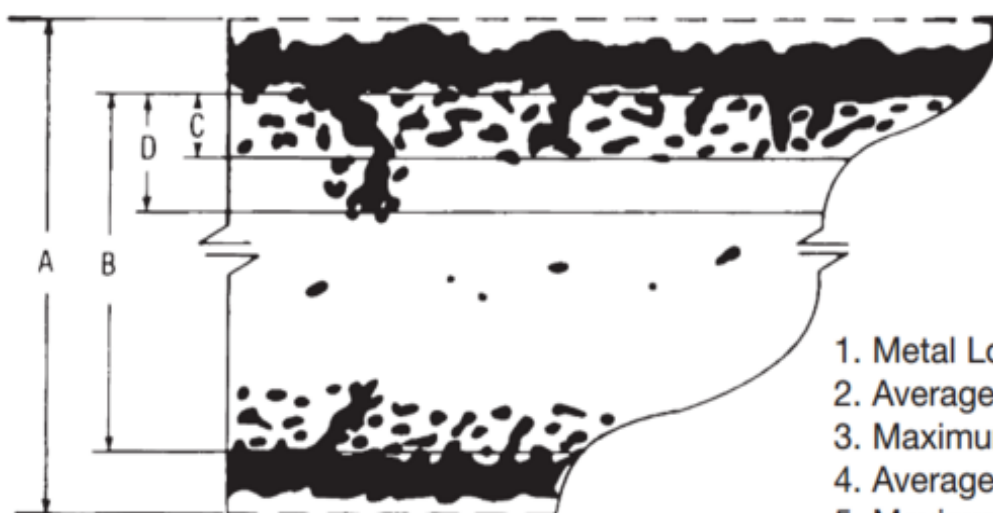
Alloy	1800°F (980°C)/1008 h				2000°F (1095°C)/1008 h				2100°F (1150°C)/1008 h				2200°F (1205°C)/1008 h			
	Average Metal Loss**		Average Metal Affected***		Average Metal Loss**		Average Metal Affected***		Average Metal Loss**		Average Metal Affected***		Average Metal Loss**		Average Metal Affected***	
	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm	mils	µm
214®	0.1	3	0.3	8	0.1	3	0.2	5	0.1	3	0.5	13	0.1	3	0.7	18
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
X	0.2	5	1.5	38	1.3	33	4.4	112	3.6	91	6.1	115	-	-	-	-
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
HR-120®	0.4	10	2.1	53	1	25	4.4	112	7.9	201	10.1	257	21.7	551	25.4	645
556	0.4	10	2.3	58	1.5	38	6.9	175	10.4	264	17.5	445	-	-	-	-
600	0.3	8	2.4	61	0.9	23	3.3	84	2.8	71	4.8	122	5.1	130	8.4	213
RA-330®	0.3	8	3.0	76	0.8	20	6.7	170	-	-	-	-	-	-	-	-
800HT	0.5	13	4.1	104	7.6	193	11.6	295	11	279	15.0	381	-	-	-	-
HR-160®	0.7	18	5.5	140	1.7	43	10.3	262	2.5	64	16.0	406	13.5	345	62.9	1598
304 SS	5.5	140	8.1	206	NA	NA	>19.6	>498	NA	NA	>19.5	>495	-	-	-	-
316 SS	12.3	312	14.2	361	NA	NA	>17.5	>445	NA	NA	>17.5	>445	-	-	-	-
446 SS	-	-	-	-	13	330	14.4	366	NA	NA	>21.5	>546	-	-	-	-

*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.

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

***Average Metal Affected is sum of Metal Loss and Average Internal Penetration.

Metallographic Technique used for Evaluating Environmental 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 = $(A - B) / 2 + D$

Oxidation Resistance Continued

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

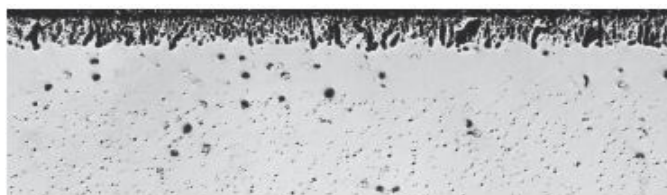
Microstructures shown are for coupons exposed for 1008 hours at 2100°F (1150°C) in air flowing at 7.0 feet/minute (213.4 cm/minute) past the samples. Samples were descaled by cathodically charging the coupons while they were immersed in a molten salt solution. The black area shown at the top of each picture represents actual metal loss due to oxidation. The data clearly show HAYNES® 214® alloy is only slightly affected by the exposure, while other nickel-chromium alloys, such as alloys 600 and 601, and iron-nickel-chromium alloys, such as RA330® alloy, all exhibit significantly more oxidation damage. Of particular importance is the almost total absence of internal attack for the 214® alloy. This contrasts markedly with the very substantial amount of internal attack evidenced by the alloy 601 and RA330® alloy tests coupons. The nature of this internal attack, as illustrated by the photomicrographs, is common for alloys containing 1-2% aluminum or silicon. Such levels of these elements do promote chromium oxide scale adherence, but do not afford improved resistance to oxide penetration below the scale.



HAYNES® 214® alloy
Average Metal Affected
= 0.5 mils (13 µm)



Alloy 600
Average Metal Affected
=4.8 mils (122µm)



Alloy 601
Average Metal Affected
=6.5 mils (165 µm)



RA330® alloy
Average Metal Affected
=8.7 mils (221 µm)

Oxidation Resistance Continued

Comparative Burner Rig Oxidation Resistance

Alloy	1800°F (980°C)/1000 Hours				2000°F (1095°C)/500 Hours				2100°F (1150°C)/200 Hours			
	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
214®	1.5	38	1.8	46	1.2	30	1.5	38	2.0	51	2.1	53
230®	2.8	71	5.6	142	7.1	180	9.9	251	6.4	163	13.1	333
556®	4.1	104	6.7	170	9.9	251	12.1	307	11.5	292	14	356
X	4.3	109	7.3	185	11.6	295	14.0	356	13.9	353	15.9	404
HR-160®	5.4	137	11.9	302	12.5	318	18.1	460	8.7	221	15.5	394
601	5.7	145	Through thickness		-	-	-	-	16.3	414	Through thickness	
HR-120®	6.3	160	8.3	211	-	-	-	-	-	-	-	-
RA330	8.7	221	10.5	267	15.4	391	17.9	455	11.5	292	13.0	330
310 SS	16.0	406	18.3	465	-	-	-	-	Consumed		-	-
800H	22.9	582	Through thickness		Consumed after 300 h		-	-	Consumed		-	-
800HT	23.3	592	Through thickness		Consumed after 365 h		-	-	Consumed		-	-
304 SS	Consumed		Consumed		-	-	-	-	-	-	-	-

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

** Average Metal Affected is sum of Metal Loss and Average Internal Penetration

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

Alloy	1800°F (980°C)				2000°F (1095°C)				2100°F (1150°C)				2200°F (1205°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
214®	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.4	36
230®	0.1	3	2.5	64	3.4	86	11	279	28.5	724	34.4	874	39	991	64	1626
X	0.2	5	2.8	71	17.1	434	26.2	665	51.5	1308	55.4	1407	>129.0	>3277	>129.0	>3277
HR-120®	0.5	13	3.3	84	18.1	460	23.2	589	33.6	853	44	1118	>132.0	>3353	>132.0	>3353
556	0.5	13	6.2	157	15	381	24.1	612	-	-	-	-	-	-	-	-
HR-160®	1.7	43	13.7	348	7.2	183	30.8	782	12	305	45.6	1158	13.5	345	62.9	1598

*Flowing air at a velocity of 7.0 ft/min (213.4 cm/min) past the samples. Samples cycled to room temperature once per month.

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

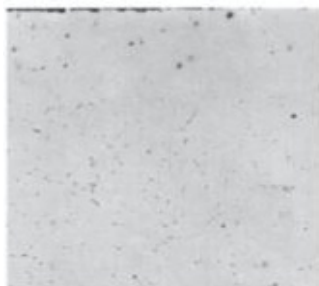
***Average Metal Affected is sum of Metal Loss and Average Internal Penetration

Oxidation Resistance Continued

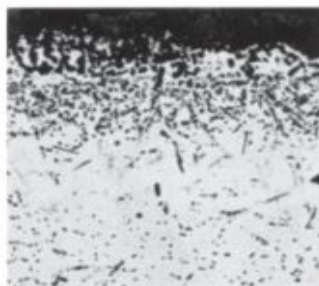
Oxidation Test Parameters

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 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 less than 500°F (260°C) and then reinserted into the flame tunnel.

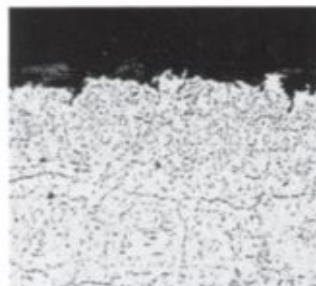
Comparative Burner Rig Oxidation Resistance at 1800°F (980°C)/1000 Hours



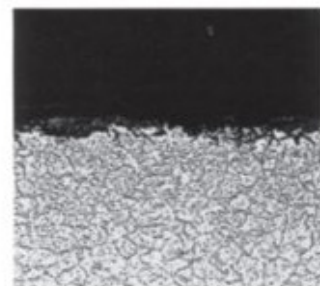
HAYNES® 214® alloy
Average Metal Affected
= 1.8 mils (45.7 µm)



Alloy 601
Average Metal Affected
> 23 mils (> 584 µm)

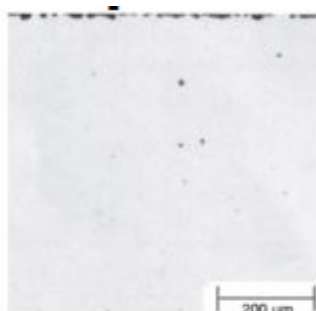


RA330® alloy
Average Metal Affected
= 10.5 mils (267 µm)

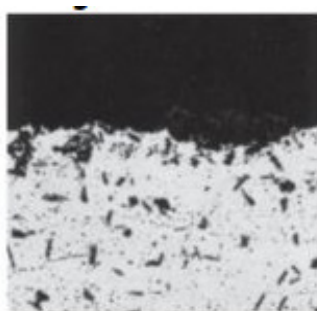


Alloy 800H
Average Metal Affected
> 38 mils (> 965 µm)

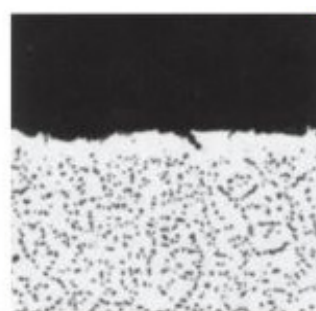
Comparative Burner Rig Oxidation Resistance at 2000°F (1095°C)/500 Hours



HAYNES® 214® alloy
Average Metal Affected
= 1.2 mils (30 µm)



Alloy 601
Average Metal Affected
> 23 mils (> 584 µm)



RA330® alloy
Average Metal Affected
= 17.9 mils (455 µm)



Alloy 800H
Average Metal Affected
> 38 mils (> 965 µm)

Oxidation Resistance Continued

Water Vapor

1200°F (650°C)

Alloy	1008h (cycled weekly) in air + 5% H_2O				1008h (cycled weekly) in air + 10% H_2O			
	Metal Loss*		Average Metal Affected**		Metal Loss*		Average Metal Affected**	
	mils	μm	mils	μm	mils	μm	mils	μm
214[®]	0	0	0	0	0	0	0.08	2
230[®]	0	0	0.05	2	0.01	0	0.2	5
625	0	0	0.07	2	0.01	0	0.26	7
X	0	0	0.18	4	0.01	0	0.13	3
HR-120[®]	0	0	0.23	6	0.02	0	0.55	14
347SS	0.02	0	0.28	7	0.03	1	0.34	9
253MA	0.05	1	0.5	13	0.08	2	1.12	29

1400°F (760°C)

Alloy	1008h (cycled weekly) in air + 5% H_2O				1008h (cycled weekly) in air + 10% H_2O				1008h (cycled weekly) in air + 20% H_2O			
	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
214[®]	0.01	1	0.05	1	0.01	0	0.16	4	0.01	0	0.01	0
230[®]	0.03	1	0.24	6	0.03	1	0.21	6	0.04	1	0.14	4
625	0.02	1	0.13	3	0.04	1	0.27	7	0.05	1	0.25	6
HR-120[®]	0.04	1	0.24	6	0.04	1	0.29	7	0.08	2	0.68	17
X	0.04	1	0.32	8	0.04	1	0.3	8	0.06	2	0.36	9
617	-	-	-	-	0.05	1	0.45	11	-	-	-	-
253MA	0.04	1	0.42	11	0.08	2	0.68	17	0.19	5	0.99	25
347SS	0.04	1	0.46	12	0.18	5	0.88	22	0.78	20	1.98	50

Oxidation Resistance Continued

1600°F (870°C)												
Alloy	1008h (cycled weekly) in air + 5%H ₂ O				1008h (cycled weekly) in air + 10%H ₂ O				1008h (cycled weekly) in air + 20%H ₂ O			
	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
214[®]	0.05	1	0.21	5	0.05	1	0.26	7	0.04	1	0.12	3
625	0.11	3	0.41	11	0.11	3	0.5	12	0.11	3	0.6	15
X	0.09	2	0.38	10	0.03	1	0.5	13	0.13	3	1.17	30
230[®]	0.06	1	0.32	8	0.07	2	0.53	13	0.08	2	1.11	28
HR-120[®]	0.08	2	0.54	14	0.09	2	0.68	17	0.16	4	1.06	27
617	-	-	-	-	0.08	2	0.88	22	-	-	-	-
347SS	0.65	16	1.48	38	0.86	22	1.48	38	7.31	186	9.34	237
253MA	0.12	3	0.43	11	0.66	17	1.59	41	0.64	16	1.67	42

1800°F (980°C)												
Alloy	1008h (cycled weekly) in air + 5%H ₂ O				1008h (cycled weekly) in air + 10%H ₂ O				1008h (cycled weekly) in air + 20%H ₂ O			
	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
214[®]	0.04	1	0.24	6	0.05	1	0.55	14	0.04	1	0.64	16
188	0.13	3	1.43	36	0.14	4	1.64	42	0.18	5	1.48	38
230[®]	0.17	4	1.47	37	0.18	5	1.38	35	0.19	5	1.59	40
625	0.32	8	1.62	41	0.16	4	1.46	37	0.36	9	1.66	42
X	0.27	7	1.77	45	0.26	7	1.66	42	0.27	7	1.77	45
556[®]	-	-	-	-	-	-	-	-	0.35	9	1.85	47
617	0.3	8	2	51	0.15	4	1.65	42	0.39	10	1.99	50
HR-120[®]	0.34	9	1.94	49	0.36	9	1.66	42	0.38	10	2.08	53
800HT	-	-	-	-	-	-	-	-	2.47	63	5.07	129
HR-160[®]	-	-	-	-	-	-	-	-	0.77	20	5.57	141

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

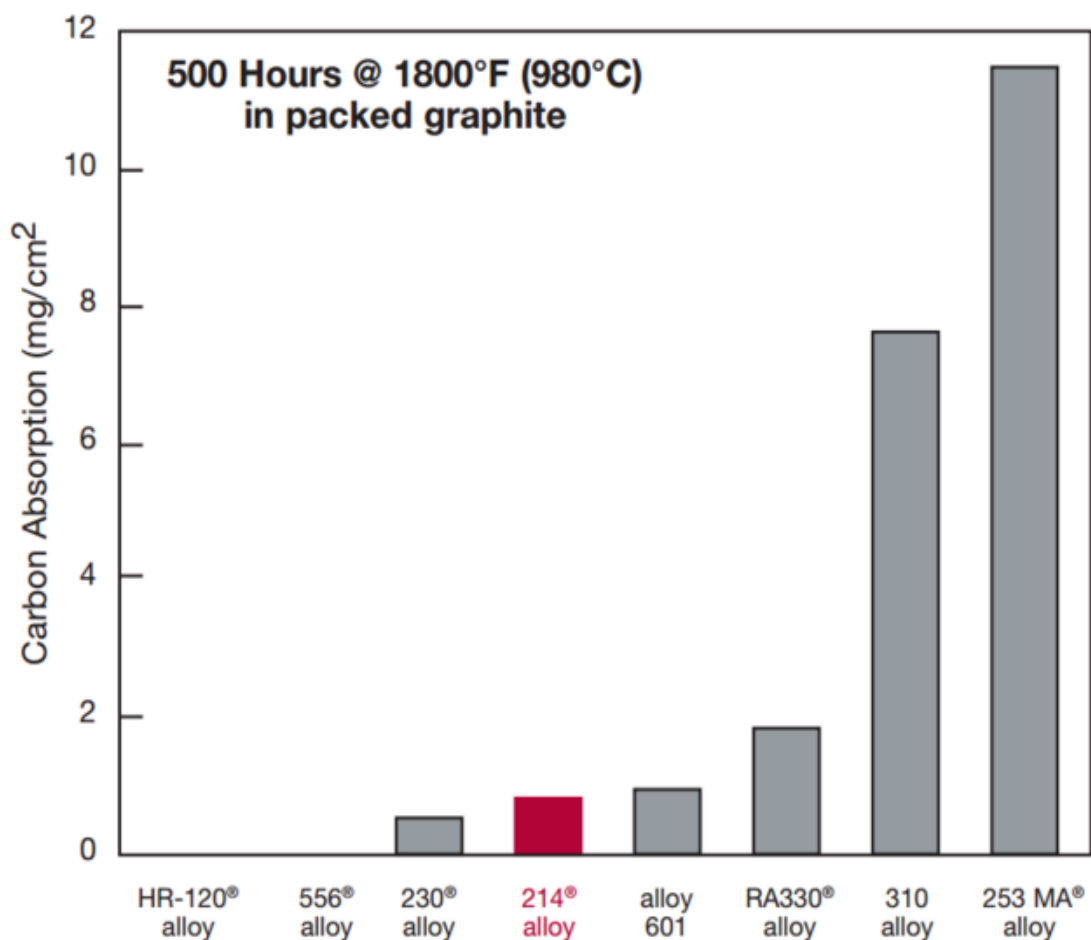
** Average Metal Affected is sum of Metal Loss and Average Internal Penetration

Carburization Resistance

HAYNES® 214® alloy has very good resistance to carburization, as measured in both packed graphite exposure tests and mixed gas exposure tests. Results for these tests are presented in the following pages. All results are presented in terms of the mass of carbon absorption per unit area, which was obtained from the equation $M = C(W/A)$ where M = the mass of carbon absorption per unit area (mg/cm^2). C = difference in carbon (weight fraction) before and after exposure, W = weight of the unexposed specimen (mg) and A = surface area of the specimen exposed to the test environment (cm^2).

Packed Carburization Resistance

Carbon absorption observed for 214® alloy following 500 hour exposure in packed graphite at 1800°F (980°C) was very low, as shown below. While superior resistance was exhibited by HAYNES HR-120® and 556® alloys, other alloys tested exhibited significantly greater carbon absorption. In particular, the resistance to carburization of 214® alloy was far better than that for the stainless steel type materials.



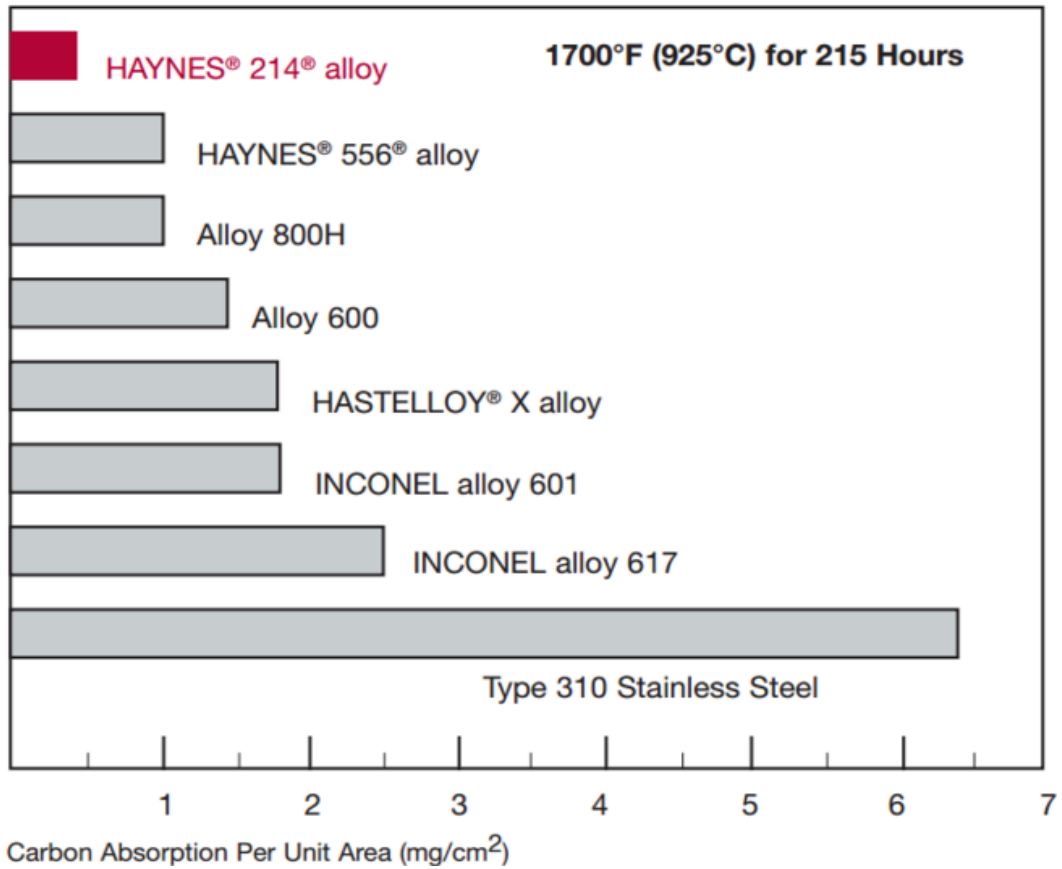
Mixed Gas Carburization Tests

Carbon absorption observed for 214® alloy following exposure at both 1700°F (925°C) and 1800°F (980°C) to a carburizing gas mixture was significantly lower than that for all other materials tested. This is shown in the graphs on the following pages. For these tests, the exposure was performed in a gas environment consisting of (by volume %) 5.0% H_2 , 5.0% CO , 5.0% CH_4 and the balance argon. The calculated equilibrium composition for the test environments are shown together with the results on the following pages.

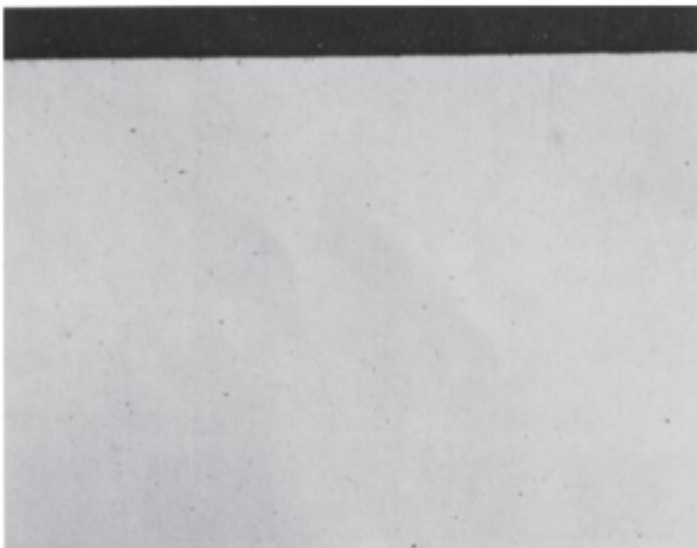
Carburization Resistance Continued

Comparative 1700°F (925°C) Mix Gas Carburization Tests

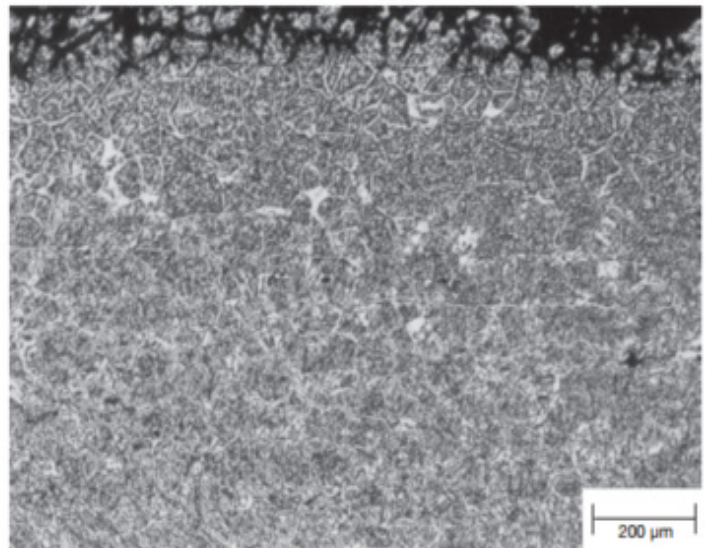
The calculated equilibrium composition (volume %) at 1700°F (925°C) and one atma was 14.2% H₂, 4.74% CO, 0.0044% CO₂, 0.032 CH₄ and balance Argon. The activity of Carbon was 1.0 and the partial pressure of Oxygen was 2.47 x 10⁻²² atma.



Typical Carburized Microstructures (Unetched) After Exposure For 215 Hours At 1700°F (925°C)



HAYNES® 214® alloy

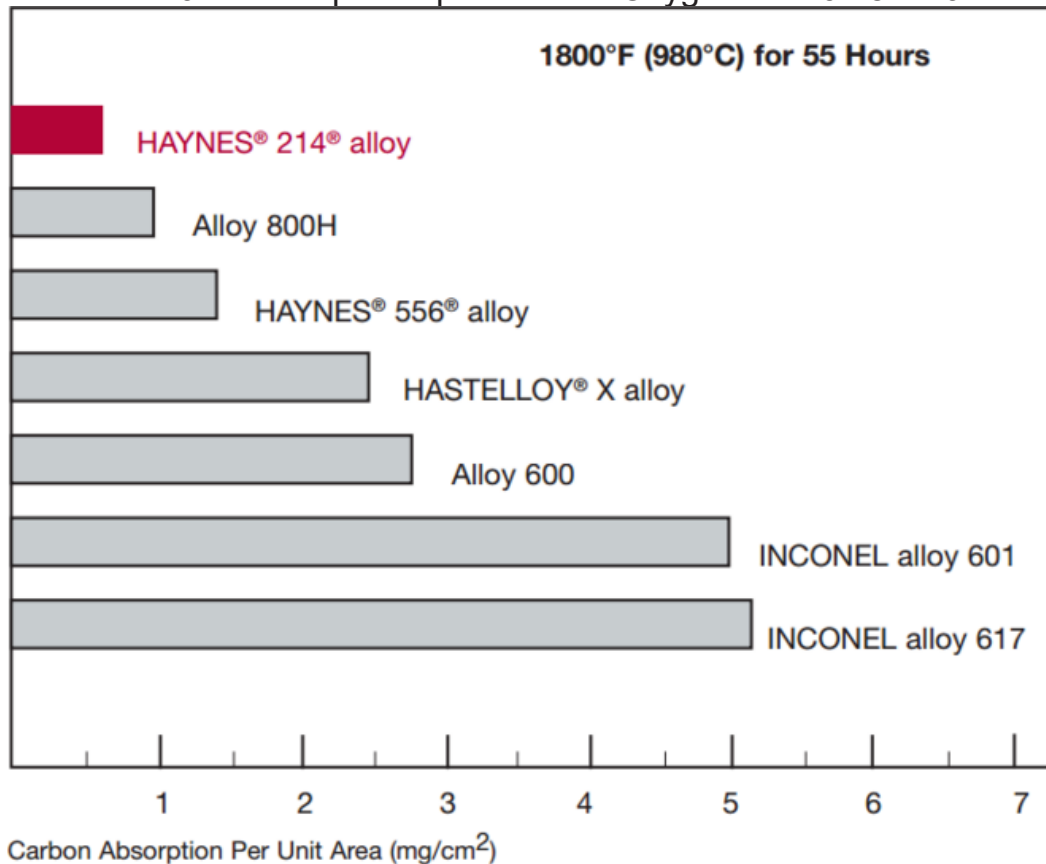


Type 310 Stainless Steel

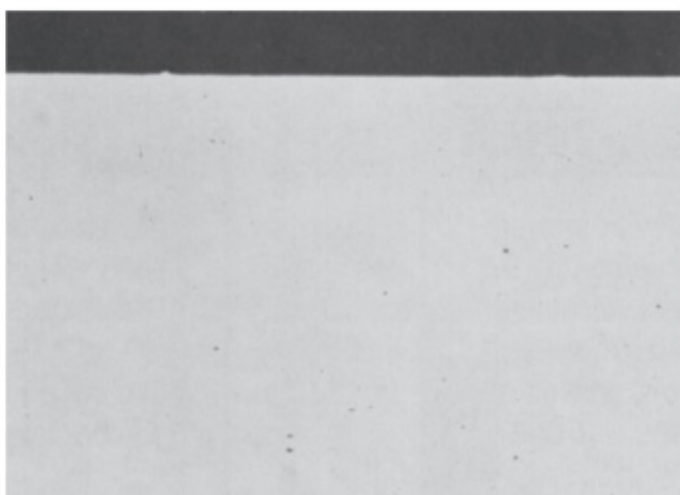
Carburization Resistance Continued

Comparative 1800°F (980°C) Mixed Gas Carburization Tests

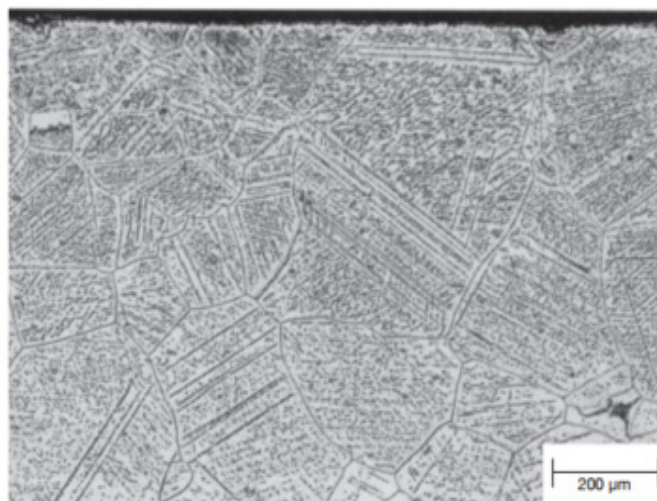
The calculated equilibrium composition (volume %) at 1800°F (980°C) and one atma was 14.2% H₂, 4.75% CO, 0.0021% CO₂, 0.024% CH₄, 0.0098% H₂O and balance argon. The activity of Carbon was 1.0 and the partial pressure of Oxygen was 6.78 x 10⁻²² atma.



Typical Carburized Microstructures (Unetched) After Exposure For 55 Hours At 1800°F (980°C)



HAYNES® 214® alloy

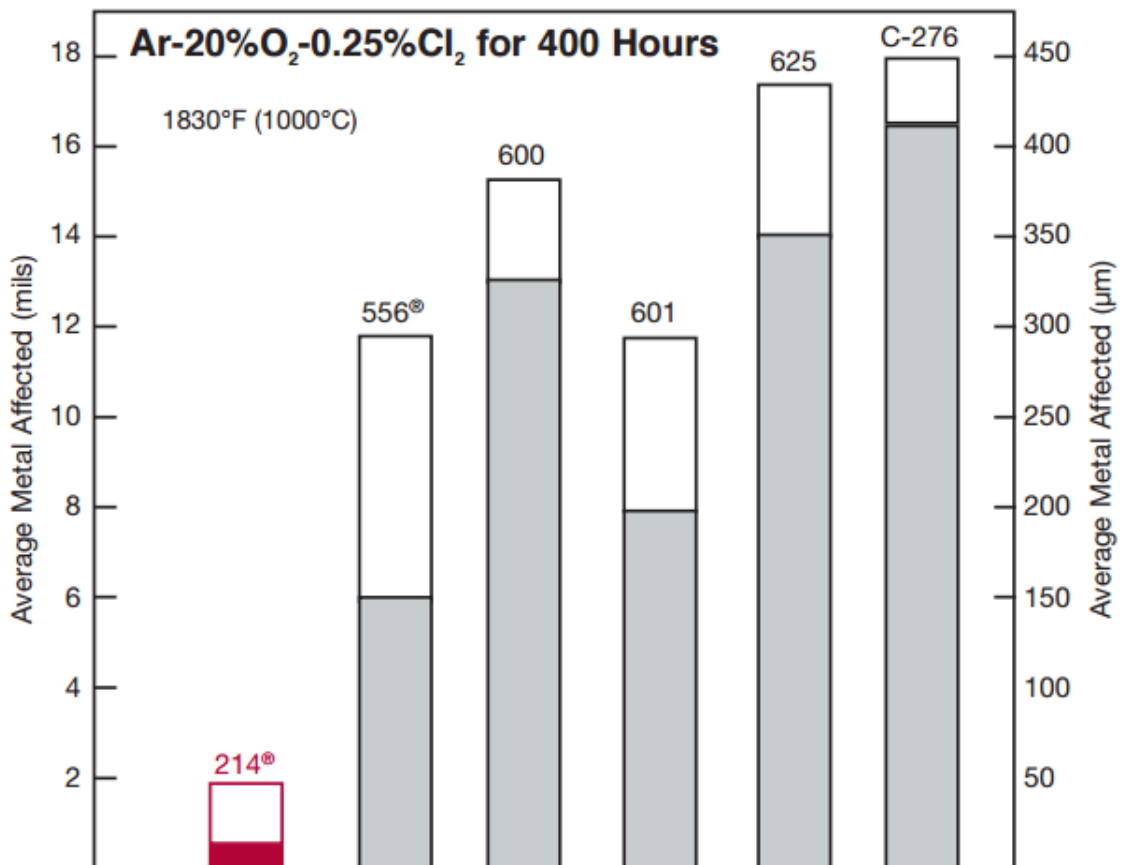
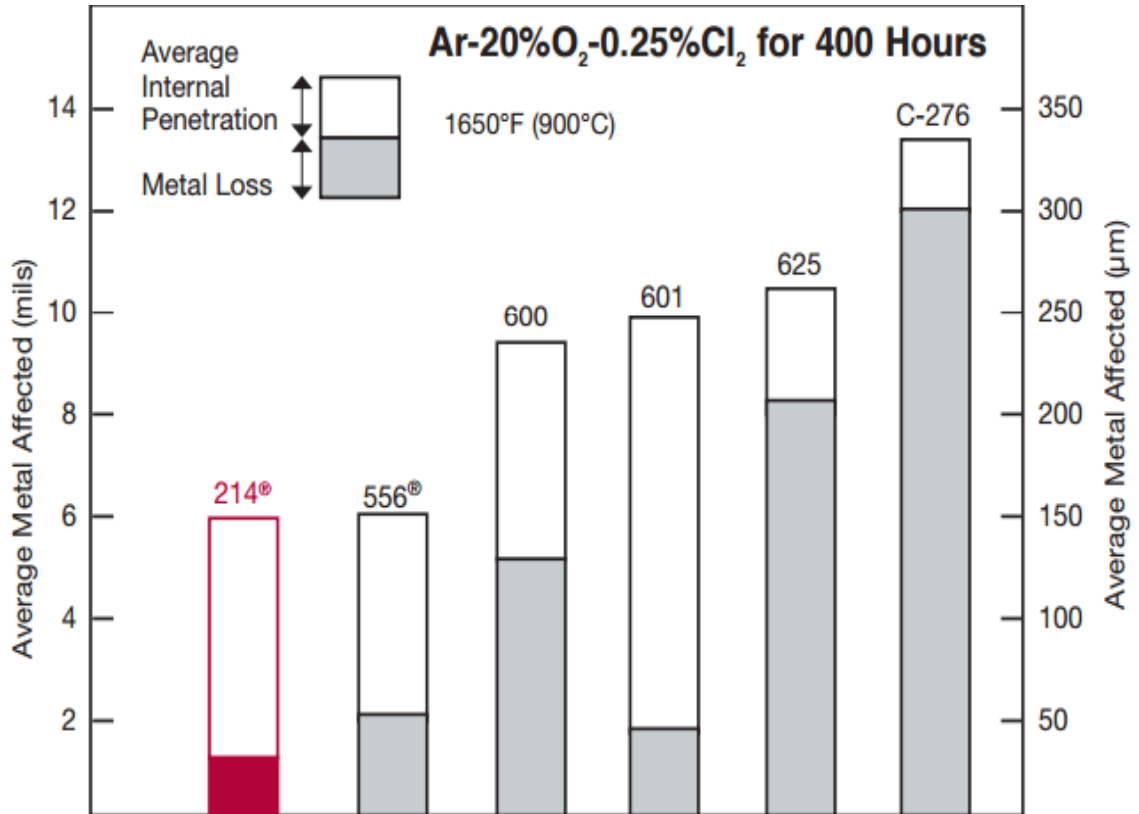


INCONEL alloy 617

Note: Alloy 617 is carburized to the center of the sample.

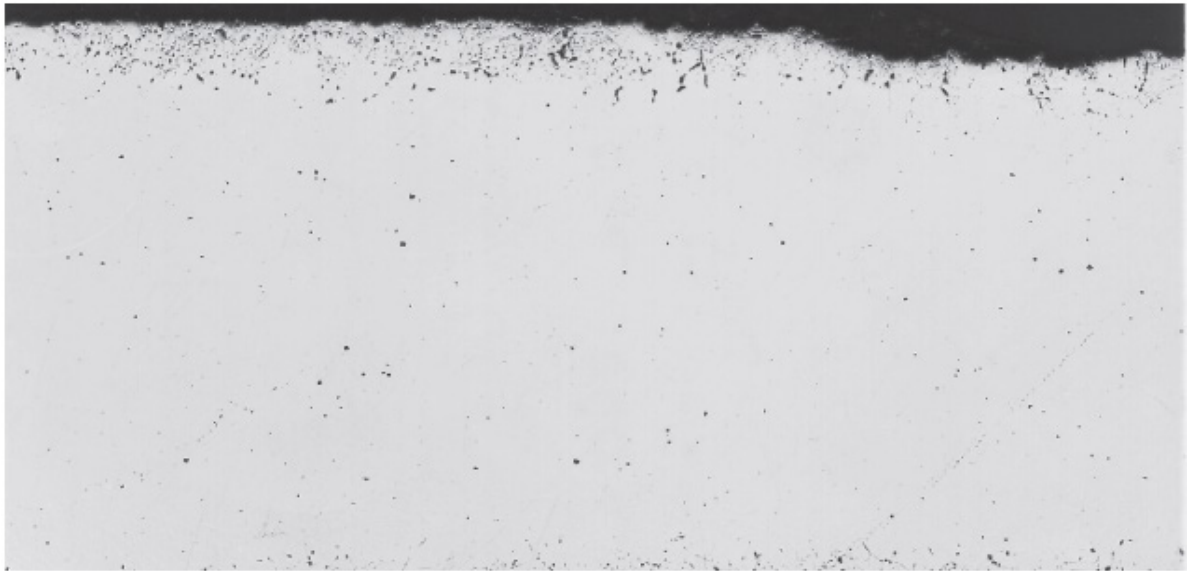
Resistance to Chlorine-Bearing Environments

HAYNES® 214® alloy provides outstanding resistance to corrosion in high-temperature, chlorinecontaminated oxidizing environments. This is particularly evident for exposures at temperatures at or above 1800°F (980°C), where the formation of the Al₂O₃-rich protective oxide scale is favored. Test results are shown for 400 hour exposures in a flowing gas mixture of Ar + 20% O₂ + 0.25% Cl₂. Note that the metal loss exhibited by 214® alloy is very low compared to other alloys tested.

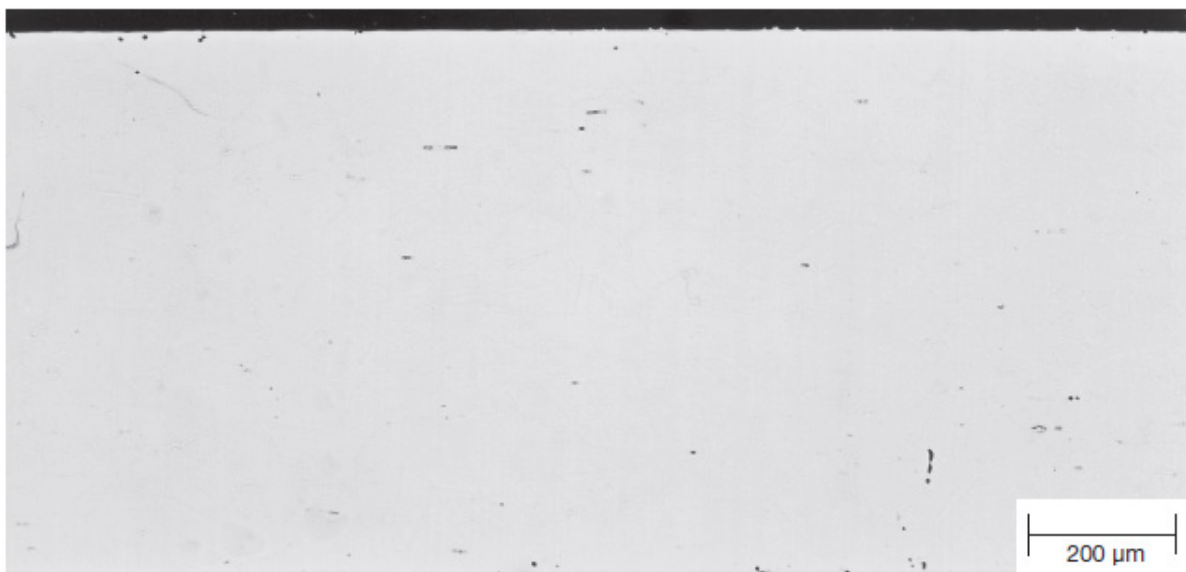


Resistance to Chlorine-Bearing Environments Continued

HAYNES® 214® alloy has also been tested in environments with higher levels of chlorine contamination. The photomicrographs below are for samples exposed to a mixture of air and 2% chlorine for 50 hours at 1830°F (1000°C). Once again, the black area at the top of each photograph represents actual metal loss experience. Alloy 601 exhibited 2.0 Mils (51 µm) of metal loss, and an average internal penetration of 6.0 Mils (152 µm), for a total average metal affected of 8.0 Mils (203 µm). Results for 214® alloy, by contrast, were 1.0 Mils (25 µm) of metal loss, 1.0 Mils (25 µm) of average internal penetration, for a total average metal affected of only 2.0 Mils (51 µm). These results are consistent with the results for lower chlorine level, longer-term tests given on the previous page.



Alloy 601



HAYNES® 214® alloy

Nitriding Resistance

While not the most resistant alloy for nitriding environments at traditional 1000°F to 1200°F (540°C to 650°C) temperatures, 214[®] alloy exhibits outstanding resistance at the higher temperatures where its protective Al₂O₃ scale can form, even in extremely low oxygen environments. Tests were performed in flowing ammonia at 1200, 1800 and 2000°F (650, 980 and 1095°C) for 168 hours. Nitrogen absorption was determined by technical 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
601	1.1	1.2	2.6
214[®]	1.5	0.3	0.2
X	1.7	3.2	3.8
800H	4.3	4.0	5.5
310 SS	7.4	7.7	9.5

Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.291 lb/in ³	RT	8.05 g/cm ³
Melting Range	2475-2550°F	-	1355-1400°C	-
Electrical Resistivity	RT	53.5 μohm-in	RT	135.9 μohm-cm
	200°F	53.9 μohm-in	100°C	136.9 μohm-cm
	400°F	53.9 μohm-in	200°C	136.9 μohm-cm
	600°F	53.9 μohm-in	300°C	136.9 μohm-cm
	800°F	54.3 μohm-in	400°C	137.7 μohm-cm
	1000°F	54.3 μohm-in	500°C	137.9 μohm-cm
	1200°F	53.5 μohm-in	600°C	136.8 μohm-cm
	1400°F	51.6 μohm-in	700°C	133.7 μohm-cm
	1600°F	49.6 μohm-in	800°C	129.2 μohm-cm
	1800°F	48.0 μohm-in	900°C	124.9 μohm-cm
	1900°F	47.6 μohm-in	1000°C	121.6 μohm-cm
	2000°F	47.6 μohm-in	1050°C	120.9 μohm-cm
	2100°F	48.0 μohm-in	1100°C	121.0 μohm-cm
	2200°F	48.4 μohm-in	1150°C	121.9 μohm-cm
	-	-	1200°C	122.9 μohm-cm
Thermal Conductivity	RT	83 Btu-in/ft ² -hr-°F	RT	12.0 W/m-°C
	200°F	88 Btu-in/ft ² -hr-°F	100°C	12.8 W/m-°C
	400°F	99 Btu-in/ft ² -hr-°F	200°C	14.2 W/m-°C
	600°F	112 Btu-in/ft ² -hr-°F	300°C	15.9 W/m-°C
	800°F	132 Btu-in/ft ² -hr-°F	400°C	18.4 W/m-°C
	1000°F	153 Btu-in/ft ² -hr-°F	500°C	21.1 W/m-°C
	1200°F	175 Btu-in/ft ² -hr-°F	600°C	23.9 W/m-°C
	1400°F	200 Btu-in/ft ² -hr-°F	700°C	26.9 W/m-°C
	1600°F	215 Btu-in/ft ² -hr-°F	800°C	29.7 W/m-°C
	1800°F	225 Btu-in/ft ² -hr-°F	900°C	31.4 W/m-°C
	2000°F	234 Btu-in/ft ² -hr-°F	1000°C	32.7 W/m-°C
	2200°F	255 Btu-in/ft ² -hr-°F	1100°C	34.0 W/m-°C
	-	-	1200°C	36.7 W/m-°C
	Thermal Diffusivity	RT	5.2 x 10 ⁻³ in ² /sec	RT
200°F		5.7 x 10 ⁻³ in ² /sec	100	34.5 x 10 ⁻³ cm ² /sec
400°F		6.2 x 10 ⁻³ in ² /sec	200	36.6 x 10 ⁻³ cm ² /sec
600°F		6.8 x 10 ⁻³ in ² /sec	300	39.4 x 10 ⁻³ cm ² /sec
800°F		7.5 x 10 ⁻³ in ² /sec	400	43.2 x 10 ⁻³ cm ² /sec
1000°F		7.9 x 10 ⁻³ in ² /sec	500	47.2 x 10 ⁻³ cm ² /sec
1200°F		8.1 x 10 ⁻³ in ² /sec	600	49.5 x 10 ⁻³ cm ² /sec
1400°F		8.2 x 10 ⁻³ in ² /sec	700	52.9 x 10 ⁻³ cm ² /sec
1600°F		8.4 x 10 ⁻³ in ² /sec	800	51.7 x 10 ⁻³ cm ² /sec
1800°F		9.1 x 10 ⁻³ in ² /sec	900	53.3 x 10 ⁻³ cm ² /sec
2000°F		9.4 x 10 ⁻³ in ² /sec	1000	54.2 x 10 ⁻³ cm ² /sec
2175°F		5.2 x 10 ⁻³ in ² /sec	1100	58.6 x 10 ⁻³ cm ² /sec
-		-	1200	61.2 x 10 ⁻³ cm ² /sec

RT= Room Temperature

Physical Properties Continued

Physical Property	British Units		Metric Units	
Specific Heat	RT	0.108 Btu/lb.-°F	RT	452 J/Kg-°C
	200°F	0.112 Btu/lb.-°F	100°C	470 J/Kg-°C
	400°F	0.118 Btu/lb.-°F	200°C	493 J/Kg-°C
	600°F	0.124 Btu/lb.-°F	300°C	515 J/Kg-°C
	800°F	0.130 Btu/lb.-°F	400°C	538 J/Kg-°C
	1000°F	0.136 Btu/lb.-°F	500°C	561 J/Kg-°C
	1200°F	0.154 Btu/lb.-°F	600°C	611 J/Kg-°C
	1400°F	0.166 Btu/lb.-°F	700°C	668 J/Kg-°C
	1600°F	0.173 Btu/lb.-°F	800°C	705 J/Kg-°C
	1800°F	0.177 Btu/lb.-°F	900°C	728 J/Kg-°C
	1900°F	0.178 Btu/lb.-°F	1000°C	742 J/Kg-°C
	2000°F	0.179 Btu/lb.-°F	1100°C	749 J/Kg-°C
	2200°F	0.180 Btu/lb.-°F	1200°C	753 J/Kg-°C
	Mean Coefficient of Thermal Expansion	70-400°F	7.4 $\mu\text{in/in-}^\circ\text{F}$	25-200°C
70-600°F		7.6 $\mu\text{in/in-}^\circ\text{F}$	25-300°C	13.6 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
70-800°F		7.9 $\mu\text{in/in-}^\circ\text{F}$	25-400°C	14.1 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
70-1000°F		8.2 $\mu\text{in/in-}^\circ\text{F}$	25-500°C	14.6 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
70-1200°F		8.6 $\mu\text{in/in-}^\circ\text{F}$	25-600°C	15.2 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
70-1400°F		9.0 $\mu\text{in/in-}^\circ\text{F}$	25-700°C	15.8 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
70-1600°F		9.6 $\mu\text{in/in-}^\circ\text{F}$	25-800°C	16.6 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
70-1800°F		10.2 $\mu\text{in/in-}^\circ\text{F}$	25-900°C	17.6 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
70-2000°F		11.1 $\mu\text{in/in-}^\circ\text{F}$	25-1000°C	18.6 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
-		-	25-1100°C	20.2 x 10 ⁻⁶ $\mu\text{m/m-}^\circ\text{C}$
Dynamic Modulus of Elasticity	RT	31.6 x 10 ⁶ psi	RT	218 GPa
	200°F	30.6 x 10 ⁶ psi	100°C	210 GPa
	400°F	29.6 x 10 ⁶ psi	200°C	204 GPa
	600°F	28.7 x 10 ⁶ psi	300°C	199 GPa
	800°F	27.4 x 10 ⁶ psi	400°C	190 GPa
	1000°F	25.3 x 10 ⁶ psi	500°C	184 GPa
	1200°F	23.9 x 10 ⁶ psi	600°C	177 GPa
	1400°F	22.3 x 10 ⁶ psi	700°C	170 GPa
	1600°F	20.2 x 10 ⁶ psi	800°C	162 GPa
	1800°F	19.0 x 10 ⁶ psi	900°C	151 GPa
	-	-	1000°C	137 GPa

RT= Room Temperature

Tensile Properties

Cold-Rolled and Solution Annealed Sheet, 0.078 to 0.125 Inches (2.0 to 3.2 mm) Thick*

Test Temperature		Yield Strength at 0.2% Offset		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	83.6	577	141.4	975	37.3
1200	649	77.9	537	109.6	756	22.2
1400	760	72.3	498	88.2	608	20.4
1600	871	40.5	279	49.5	341	49.4
1800	982	6.0	41	9.8	68	144.8
1900	1038	3.9	27	7.3	51	153.1
2000	1093	3.0	20	5.5	38	157.1
2100	1149	2.0	14	4.0	28	159.3
2200	1204	1.4	10	3.2	22	134.6

RT= Room Temperature

Hot-Rolled and Solution Annealed Plate, 0.500 Inches (12.7 mm) Thick*

Test Temperature		Yield Strength at 0.2% Offset		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	82.2	565	138.9	960	42.8
1000	538	71.5	495	120	825	47.8
1200	649	75.9	252	114.9	790	33
1400	760	73.6	505	94.4	670	23.1
1600	871	50.4	345	66.4	460	33.6
1800	982	8.4	58	16.7	115	86.4
2000	1093	4.2	29	9	62	88.6
2100	1149	2.1	14	6.6	46	99.4
2200	1204	1.4	10	5	34	91.5

RT= Room Temperature

*Elevated temperature tensile tests for plate were performed with a strain rate that is no longer standard. These results were from tests with a strain rate of 0.005 in./in./minute through yield and a crosshead speed of 0.5 in./minute for every inch of reduced test section from yield through failure. The current standard is to use a strain rate of 0.005 in./in./minute through yield and a crosshead speed of 0.05 in./minute for every inch of reduced test section from yield through failure.

Tensile Properties Continued

Welded Tensile Tests

	Test Temperature		Yield Strength at 0.2% Offset		Ultimate Tensile Strength		Elongation
	°F	°C	ksi	MPa	ksi	MPa	%
Transverse Specimens with GTAW Welds	RT	RT	81.0	558	124.0	855	22.0
	1000	538	70.0	483	99.0	683	13.0
	1200	649	79	545	97	669	10
	1400	760	77	531	83	572	5
	1500	816	66	455	70	483	5
	1600	871	46	317	50	345	5
	1800	982	10	69	11	76	35
	2000	1093	4	28	5	34	29
All Weld Metal Specimens	RT	RT	85	586	118	814	33
	1400	760	81	558	85	586	4
	1500	816	68	469	70	483	4
	1600	871	N/A	N/A	51	352	1
	1800	982	N/A	N/A	12	83	24

Hardness

	Typical ASTM Grain Size	Average Hardness, HRBW
Plate	3.5 - 5	100
Bar	2.5 - 5.5	94
Sheet	3.5 - 5	98

Creep and Rupture Properties

Solution Annealed Sheet

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in							
			10 h		100 h		1,000 h		10,000 h	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1200	649	0.5	-	-	-	-	46	317	-	-
		1	-	-	-	-	53	365	-	-
		R	-	-	-	-	57	393	37	255
1300	704	0.5	-	-	45	310	30	207	-	-
		1	-	-	49	338	32	221	-	-
		R	-	-	51	352	33	228	21*	145*
1400	760	0.5	38	262	26	179	17.5	121	11.2*	77*
		1	42	290	29	200	18.8	130	11.7	81
		R	50	345	33	228	19.8	137	12.3	85
1500	816	0.5	23	159	15	103	8.9	61	-	-
		1	27	186	16.5	114	9.9	68	-	-
		R	32	221	20	138	11.5	79	7	48
1600	871	0.5	12.7	88	7.5	52	4.5	31	-	-
		1	15.2	105	8.7	60	4.9	34	-	-
		R	21*	145*	11.8	81	6.3	43	3.4	23
1700	927	0.5	6.5	45	3.7	26	2.1	14	-	-
		1	7.5	52	4.2	29	2.4	17	-	-
		R	9.8	68	5.6	39	3.1	21	1.8*	12*
1800	982	0.5	1.9	13	1.2	8.3	0.75*	5.2*	-	-
		1	2.2	15	1.3	9	0.83*	5.7*	-	-
		R	4.8	33	2.7	19	1.7	12	1	6.9
1900	1038	0.5	1.2	8.3	0.74*	5.1*	0.48*	3.3*	-	-
		1	1.4	10	0.88	6.1	0.55*	3.8*	-	-
		R	3.3*	23*	2	14	1.2	8.3	0.76	5.2
2000	1093	0.5	0.75	5.2	0.55	3.8	0.32	2.2	-	-
		1	0.95	6.6	0.63	4.3	0.43	3	-	-
		R	2.2*	15*	1.5	10	0.94	6.5	0.61	4.2
2100	1149	0.5	0.53	3.7	0.35	2.4	-	-	-	-
		1	0.64	4.4	0.42	2.9	0.27	1.9	-	-
		R	1.6*	11*	1.1	7.6	0.69	4.8	0.44	3
2200	1204	0.5	-	-	-	-	-	-	-	-
		1	-	-	-	-	-	-	-	-
		R	1.1*	7.6*	0.76	5.2	0.49	3.4	-	-

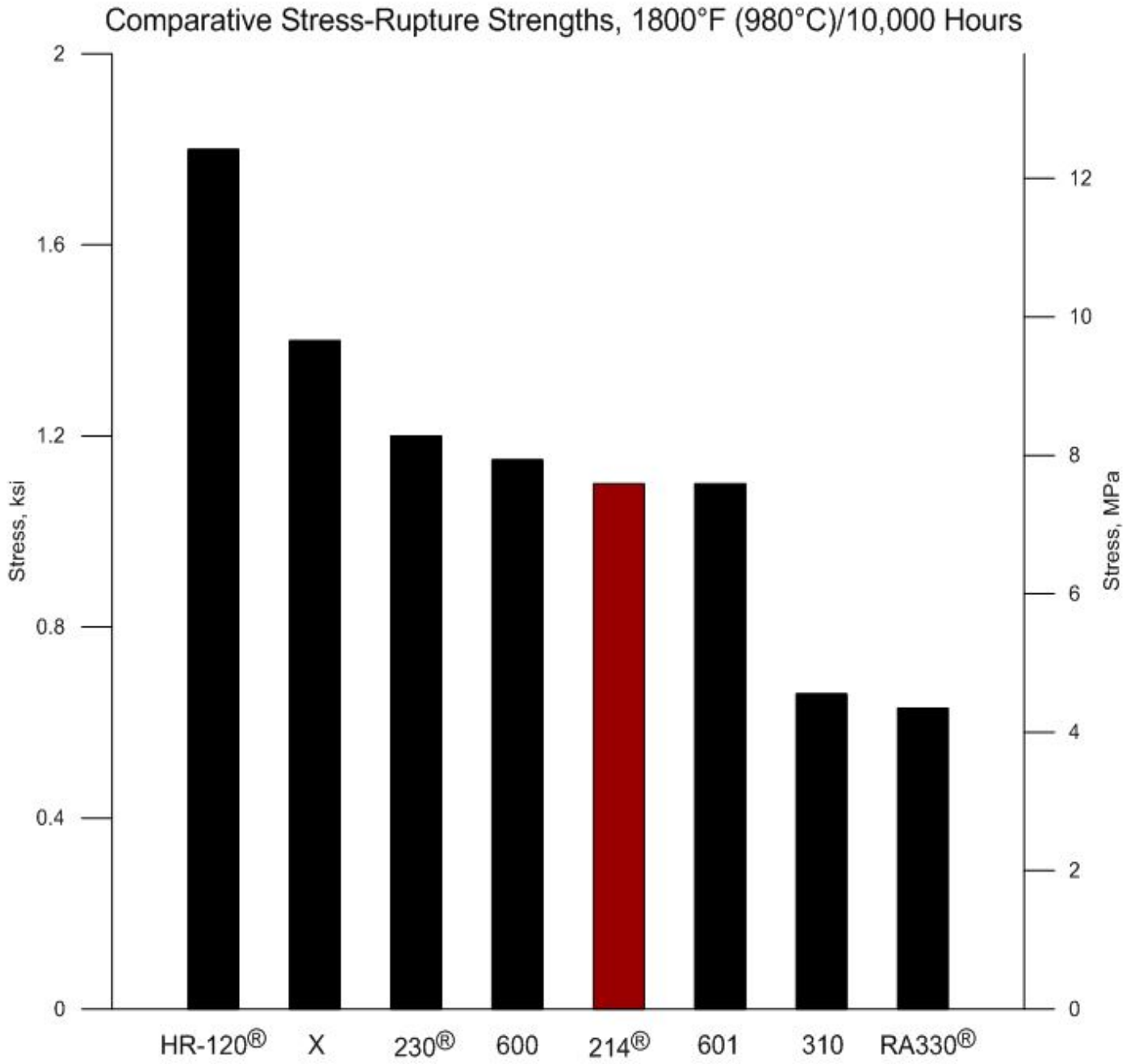
*Significant extrapolation

Creep and Rupture Properties Continued

Solution Annealed Plate

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in							
			10 h		100 h		1,000 h		10,000 h	
°F	°C	%	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1400	760	0.5	41*	283*	29	200	21	145	14*	97*
		1	44*	303*	32	221	23	159	14.5*	100*
		R	55*	379*	38	262	24	165	15	103
1500	816	0.5	26	179	19	131	12.8	88	7.8*	54*
		1	28	193	20.5	141	13.8	95	8.4*	58*
		R	35	241	23	159	15	103	9.0*	62*
1600	871	0.5	17*	117*	11.2	77	6.2	43	3.3	23
		1	20*	138*	12.2	84	6.7	46	3.7	26
		R	24*	165*	15	103	8.5	59	4.6	32
1700	927	0.5	8.5	59	4.9	34	2.6	18	1.4	10
		1	9.7	67	5.3	37	2.9	20	1.6	11
		R	11.5	79	7.1	49	4.2	29	2.4	17
1800	982	0.5	2	14	1.3	9	0.85	5.9	-	-
		1	2.2	15	1.5	10	1	6.9	0.68*	4.7*
		R	3.9	27	2.9	20	1.8	12	1.1	7.6
1900	1038	0.5	1.2	8.3	0.77	5.3	0.5	3.4	-	-
		1	1.4	10	0.91	6.3	0.6	4.1	0.39	2.7
		R	2.9	20	1.9	13	1.2	8.3	0.8	5.5
2000	1093	0.5	0.77	5.3	0.48	3.3	0.29	2	-	-
		1	0.93	6.4	0.62	4.3	0.41	2.8	0.20*	1.4*
		R	2.1*	14*	1.4	9.7	0.9	6.2	0.6	4.1
2100	1149	0.5	0.47	3.2	0.27*	1.9*	-	-	-	-
		1	0.60*	4.1*	0.35	2.4	-	-	-	-
		R	1.6*	11*	1	6.9	0.68	4.7	0.44	3
2200	1204	0.5	0.35	2.4	0.19*	1.3*	-	-	-	-
		1	0.45*	3.1*	0.26	1.8	-	-	-	-
		R	1.1*	7.6*	0.77	5.3	0.5	3.4	0.33	2.3

Creep and Rupture Properties Continued



Thermal Stability

HAYNES® 214® alloy exhibits reasonable room temperature ductility after longterm thermal exposure at intermediate temperatures. Precipitation of gamma prime phase occurs for exposures below 1750°F (955°C), along with minor chromium-rich carbides. Exposure at temperatures above about 1700°F (925°C) have little effect upon the properties of 214® alloy, but significant grain growth can occur above about 2000°F (1095°C).

Room-Temperature Tensile Properties of Sheet Following Thermal Exposure

Exposure Temperature		Exposure Time	0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C		ksi	MPa	ksi	MPa	
1400	760	0	89.4	615	141.1	975	37.3
		32	104.6	720	157.5	1085	27.6
		100	103.7	715	157.8	1090	26.1
		1000	98.3	680	156.4	1080	27.1
1600	870	0	89.4	615	141.1	975	37.3
		32	81.6	565	139.7	965	35
		100	76.9	530	135.5	935	35.1
		1000	71.6	495	132.5	915	39.9
1800	980	0	89.4	615	141.1	975	37.3
		32	84.6	585	137.5	950	38
		100	84.7	585	137.7	950	34.2
		1000	87.9	605	139.6	965	35.2

Hot Working

Hot Working

When planning to hot work HAYNES® 214® alloy one should first review the metallurgy of the alloy. With an understanding of its metallurgical characteristics, many options become available to the manufacturer who wishes to hot deform 214® alloy.

Introduction

HAYNES® 214® alloy (Ni base; Cr 16; Fe 3; Al 4.5; Y present) is different from most other alloys because it is nickel base and contains aluminum to create its protective alumina surface film. The aluminum also causes the intermetallic compound, Ni₃Al, to form rapidly at temperatures between about 1000°F (540°C) and 1750°F (950°C). The intermetallic phase, commonly called gamma prime (γ'), greatly strengthens the alloy, but also reduces the ductility from about 90% tensile elongation near 2000°F (1095°C) to about 15% tensile elongation in the 1300°F (700°C) to 1400°F (760°C) range. This property is shown in the accompanying tensile property graphs.

Grain size of the hot worked part is a function of starting grain size, temperatures of hot working, stress relieving or annealing, and degree or amount of work imparted. In very broad terms, grain size of 214® alloy increases with increasing temperature and is refined by increased working or deformation.

The final grain size of a component is usually important and should be considered when planning forging or other hot working operations. Larger grain sizes tend to yield higher creep and stress rupture life in service, but tend to reduce the intermediate temperature (1200°F (650°C) to 1750°F (950°C) ductility and increases the tendency of strain age cracking to occur if the component requires welding. Resistance to the environment apparently is not affected by grain size.

Metallurgy

Hot Working Variables HAYNES® 214® alloy has been successfully hot worked in the temperature range of about 2200°F (1200°C) to 1800°F (980°C). Heat up time will vary with size and complexity of the work piece. With complex shapes with transitions from large to small cross sections, it may be beneficial to equilibrate the component at about 1600°F (870°C), before raising the temperature to the final hot working temperature. In general, the best overall results seem to be achieved by working from a furnace temperature near 2100°F (1150°C). Working the alloy quickly with substantial deformation sufficient to maintain heat within the work piece is good practice. Stopping the operation when the work piece reaches 1800°F (980°C) to minimize the chance of cracking caused by the precipitation of gamma prime and the resultant loss of ductility is strongly advised.

If only a modest amount of work is to be done, for example a finishing pass, the operator should consider reducing the furnace temperature to be used for heating the work piece to prevent excessive grain growth in the alloy. Again, stopping the working when the temperature of the piece drops to 1800°F (980°C) is recommended.

Hot Working Continued

Stress Relief and Annealing

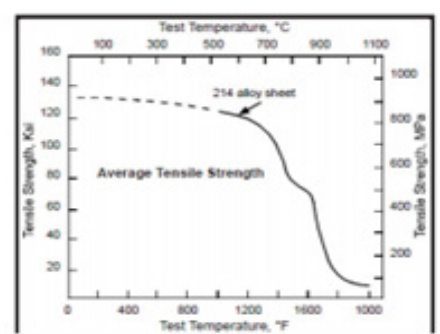
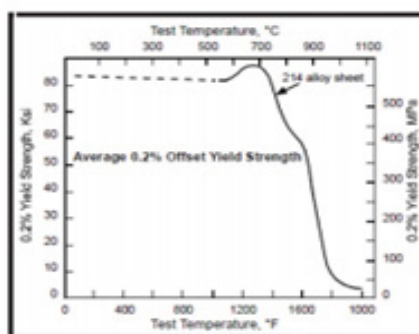
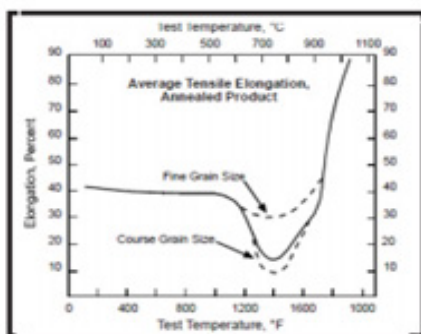
As these terms are used here, the difference between stress relieving and annealing is that annealing includes a rapid quench to prevent the precipitation of Ni_3Al , whereas a stress relieved part is typically cooled more slowly and provides more uniform cooling. Since the Ni_3Al which forms in 214[®] alloy dissolves (goes into solid solution) at temperatures above about 1800°F (980°C) causing a substantial drop in yield strength, the alloy can be effectively “stress relieved” or solution annealed at temperatures greater than this. It is the usual practice of Haynes International, Inc. to anneal product between 1950-2050°F (1065-1120°C) and rapidly cool the alloy to prevent, or minimize, the formation of gamma prime if hot deformation processes are complete. If the product is to be subsequently hot deformed, the piece is generally allowed to air cool to ambient temperature after heating.

The actual temperature chosen for stress relief or annealing should be based on the properties desired in the final product. High temperatures tend to yield large grain size, reduced mid-temperature ductility, reduced resistance to strain age cracking, better creep-rupture strengths, lower room temperature strengths, better room temperature ductility and easier machining.

Lower temperatures tend to preserve the existing mid-temperature ductility and grain size, the existing resistance to strain age cracking and result in less distortion, if a quench is used.

When a product is stress relieved and slow cooled, one can expect gamma prime to form in the alloy. This increases room temperature hardness, strength, and difficulty of machining.

The discussions presented here are based upon general experience at Haynes International, Inc., Kokomo, Indiana. They are indicative only of the results obtained at the location and should not be considered as guaranteed operating parameters:



Welding

HAYNES® 214® alloy is a precipitation-strengthened alloy. When the gamma prime phase (Ni₃Al) precipitates, the alloy undergoes a slight volumetric contraction. It is possible that stress and strain caused by welding and mechanical deformation caused by the precipitation may cause cracking.

Good welding practice to join gamma prime alloys applies to 214® alloy:

- Base metal should be normally in the solution-annealed condition
- Minimize heat input
- Minimize restraint
- Cleanliness is critical
- Use stringer beads
- Maintain interpass temperature of 200°F maximum
- Use better layers or forgiving fillers (HASTELLOY® X alloy or HASTELLOY® S alloy) as required
- A convex profile (crowned) weld bead is mandatory
- No partial penetration welds

HAYNES® 214® alloy has been joined successfully using gas tungsten arc (GTAW), gas metal arc (GMAW), shielded metal arc (coated electrode), and plasma arc (PAW) welding techniques. Matching composition filler metal is recommended for joining 214® alloy. For shielded metal-arc welding, HASTELLOY® X electrodes (AMS 5799) are suggested. For dissimilar metal joining of 214® alloy to nickel- or cobalt-base materials, HAYNES® 230-W® filler metal will generally be a good selection, but HASTELLOY® S alloy (AMS 5838) or HASTELLOY® W alloy (AMS 5786, 5787) welding products may be used. For dissimilar welding to iron-base materials, HAYNES® 556® (AMS 5831) filler metal is recommended. When using a filler metal other than 214® alloy, the environmental resistances of the weld will be inferior to that of the base metal, and a cover pass using 214® alloy wire is suggested as a means to increase environmental resistance.

Base Metal Preparation

The joint surface and adjacent area should be thoroughly cleaned before welding. All grease, oil, crayon marks, sulfur compounds and other foreign matter should be removed. It is preferable that the alloy be in the solution-annealed condition when welded. One-inch wide areas along each side of the weld joint should be ground to expose bright metal before welding. Welds should also be ground between passes.

Weld Joints

A square butt joint is used for sheet material up to 7/64 inch. A V-joint is used for butt welds in thicknesses from 7/64 inch up to 3/8 inch, a double-V or a U-joint for thicknesses of 3/8 inch to 5/8 inch (a double-V joint is preferred if both sides of the plate are accessible), and a double-U joint for thicknesses over 5/8 inch. T-joints are used when required by design. Partial penetration or fillet welds are not recommended.

V-joints should be beveled to a 60° included angle for GTAW welding, (70° for SMAW), while U-joints should have bevels with an included angle of 30° and a minimum radius of 1/4 inch. For coated electrodes, the joint should be opened up an additional 10 - 15°.

Welding Continued

Weld Penetration

For full penetration, material 12-gage (7/64 inch) and heavier should be welded from both sides. Material thinner than 12-gage may be welded from one side by using proper edge spacing to allow full penetration. Care should be exercised to prevent incomplete penetration. This condition can leave undesirable crevices and voids in the underside of the joint. Incomplete penetration in material used for high-temperature applications creates stress risers for focal points of mechanical failure.

When welding from both sides is not practical, the joint spacing should be increased and a copper backing bar used. Currents slightly higher than normal are used to obtain complete penetration. HAYNES® 214® alloy has a lower thermal conductivity than steel; therefore, when using a standard groove, it is necessary to use slightly larger clearance than would be needed for steel.

Preheating, Interpass Temperatures and Post- Weld Heat Treatment

Preheat is not usually required so long as base metal to be welded is above 32°F (0°C). It is critical to minimize heat input. The lowest amperage and voltage possible are preferred. Minimize weave, use stringer beads when possible. Avoid excessively slow travel speeds and out-of-position welding, which cause heat buildup. Excessively fast travel speeds result in teardrop-shaped weld puddles and should also be avoided to prevent centerline cracking. Interpass temperatures should be less than 200°F. Auxiliary cooling methods, including water quenching, may be used between weld passes, as needed, providing that such methods do not introduce contaminants and the part is dried.

Post weld heat treatment for 214® alloy depends on part thickness and complexity. For 214® alloy fabrications that will be in service at 1200-1800°F, weldments made of greater than 1/4" thickness, or those which have been welded into configurations which create significant residual stresses, a post weld annealing heat treatment is suggested. The objective of a post weld heat treatment is to minimize and eliminate residual stress in the assembly.

A heat treatment at a metal temperature between 1900°F and 2000°F has been successful. The metal at temperature as little as 5 minutes is usually sufficient. If no additional welding or forming is to be performed, the fabrication may be air cooled, otherwise rapid cooling is advised.

Care must be taken when annealing. Heating 214® alloy through the temperature range of 1200-1800°F will cause gamma prime (Ni_3Al) to precipitate. This gamma prime precipitation results in a net shrinkage, as well as an increase in strength and corresponding loss of ductility. In weldments and other highly stressed components, strain-age cracking may occur. This occurs when the residual stresses from forming and welding, augmented by stresses caused by precipitation, exceed the rupture strength of the base metal. It is important to heat the material through the 1200-1800°F temperature range as rapidly as possible. Do not stress relieve in the 1200-1800°F temperature range.

Torch heating or heating methods employing direct flame impingement on the fabrication should be avoided. Heating has been successfully done in an air atmosphere, as well as a protective atmosphere.

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