HAYNES® 214® alloy

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*

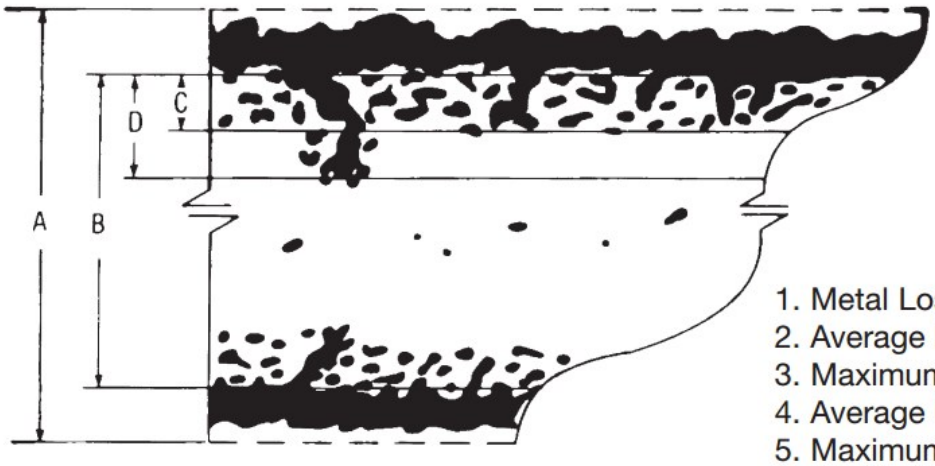
Alloy	1800°F (980°C)/1008 Hours				2000°F (1095°C)/1008 Hours				2100°F (1150°C)/1008 Hours				2200°F (1205°C)/1008 Hours			
	Average Metal Loss**		Average Metal Affected***		Average Metal Loss**		Average Metal Affected***		Average Metal Loss**		Average Metal Affected***		Average Metal Loss**		Average 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

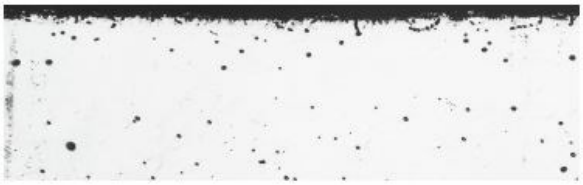


1. Metal Loss = (A - B)/2
2. Average Internal Penetration = C
3. Maximum Internal Penetration = D
4. Average Metal Affected = ((A - B)/2) + C
5. Maximum Metal Affected = (A - B)/2) + D

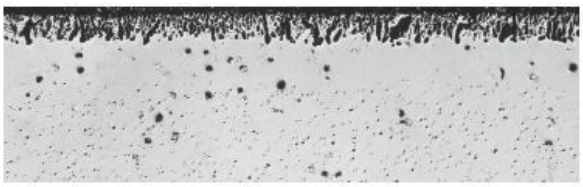
Comparative Oxidation in Flowing Air 2100°F (1150°C)

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.

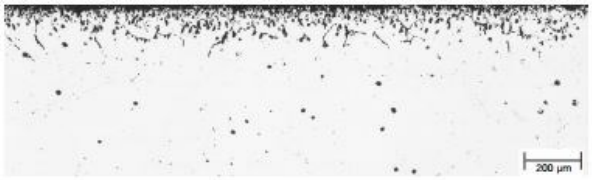
HAYNES® 214® alloy
Average Metal Affected
= 0.5 mils (13 µm)



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)

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 highâ€temperature sheet (0.060 â€0.125”) alloys exposed for 360 days (8,640â€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
HRâ€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

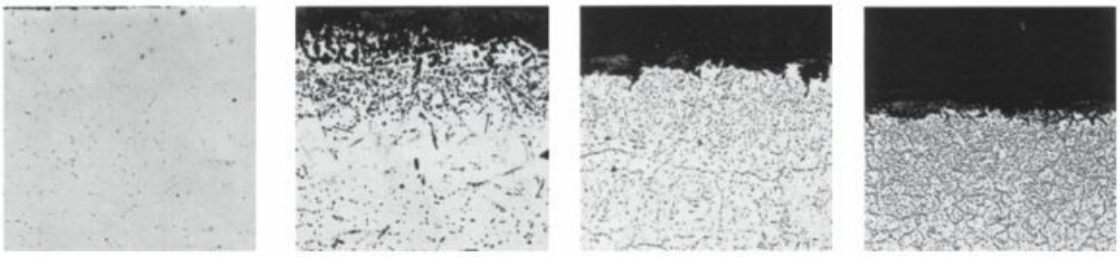
*Flowing air at a velocity of 7.0 ft/min (213.4 cm/min) past the samples. Samples cycled to room temperature once per month.
** Metal loss was calculated from final and initial metal thicknesses; i.e. ML = (OMT – FMT) /2
***Average Metal Affected is sum of Metal Loss and Average Internal Penetration

Oxidation Test Paramerters

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

(Black areas of micros indicates actual metal loss)



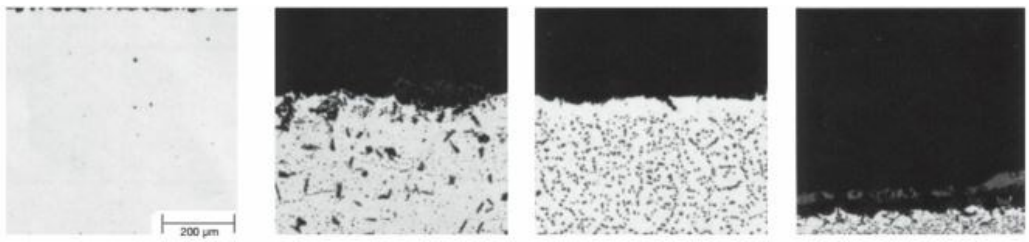
HAYNES® 214® alloy
Average Metal Affected
= 1.8 mils (45.7 µm)

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)

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
HRâ€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
HRâ€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

1600°F (870°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®	**0.05**	**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
HRâ€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_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®	**0.04**	**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
HRâ €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