ROLLED ALLOYS

DATA SHEET RA333®

THE GLOBAL LEADER IN SPECIALTY ALLOYS

HEAT RESISTANT ALLOYS

ROLLED ALLOYS
The world's heat, corrosion, titanium, and aerospace alloy specialists

Introduction

Features

- Outstanding long-term oxidation resistance to 2200°F.
- Exceptional carburization resistance
- Excellent thermal shock and fatigue life
- Hot salt corrosion resistance
- Good metal dusting (catastrophic carburization) resistance
- Resistance to chloride and polythionic acid stress corrosion
- Sulfuric and nitric acid corrosion resistance

Applications

- Tube hangers in refineries and power boilers
- Heat treating muffles, retorts and fixtures
- Radiant tubes
- Flare tips
- Stack dampers
- Rotary kilns
- Molten glass process equipment
- Furnace fans and shafts
- Gas turbine combustion chambers
- Carburizing furnace conveyor chains, belt pins

Chemical Composition, %

	min.	max.
Nickel	44.00	47.00
Chromium	24.00	27.00
Molybdenum	2.50	4.00
Cobalt	2.50	4.00
Tungsten	2.50	4.00
Carbon	--	0.08
Silicon	0.75	1.50
Manganese	--	2.00
Phosphorus	--	0.030
Sulfur	--	0.030
Iron		Remainder

UNS N06333 W. Nr. 2.4608

Performance Profile

RA333 is a high chromium nickel base superalloy with outstanding resistance to high temperature oxidation and carburization.

RA333 has good strength and exceptional ability to handle the repeated thermal shock of liquid quenching.

RA333 is one of the few materials that can withstand corrosive environments ranging from aqueous to white heat.

RA333 is used for muffles at 2200°F, dampers in 13% SO_2 at 1800°F, and for refinery flare tips. Upon shutdown, RA333 resists attack by sulfuric acid formed below the dew point. The alloy also resists chloride and polythionic acid stress corrosion cracking.

RA333 has exceptional resistance to molten glass and has replaced platinum spinnerets in fiberglass manufacture.

RA333 explosive forming die. Used in fabrication of the space shuttle engines.

Specifications

UNS N06333

Product Form	ASTM	AMS
Plate, sheet and strip	B 718	5593
Bar, forgings	B 719	5717
Welded pipe	B 723	--
Welded tube	B 726	--
Seamless pipe and tube	B 722	--

Welding Products

RA333 GMAW and GTAW wire UNS N06333

RA333 SMAW electrodes UNS W86333

RA333 may be welded by plasma arc, gas tungsten arc, gas metal arc or shielded metal arc, and resistance welded. Submerged arc welding requires a strongly basic flux, such as Böhler Thyssen's RECORD NiCrW or Avesta Flux 805, and low heat input. Sheet gauges may be autogenous GTA welded if necessary.

RA333 weld fillers develop a fluid puddle and may be used at a lower heat input than other nickel base alloys. RA333 covered electrodes are particularly useful for weld repairing both wrought and cast heat resistant alloy furnace components.

Suggested Welding Parameters

Shielded Metal Arc, RA333 AC/DC Electrodes

Electrode dia., inch (mm)	3/32 (2.4)	1/8 (3.2)	5/32 (4.0)	3/16 (4.8)
Current (DCRP)				
Range, [a]	40	70	100	125
Amperes, [b]	70	100	135	180

a. low end of range preferred for out-of-position welding, and in multi-pass welding to minimize HAZ fissures in prior weld beads.

b. add 5-10 amperes when using AC current.

Gas Tungsten Arc

Base Metal Thick-ness, inch	Electrode dia., inch	RA333 wire inch	Current DCSP, amp-eres	Voltage, V
1/16-1/8	3/32	1/16 or 1/32	50-90	12
1/8-1/4	3/32-1/8	3/32 or 1/8	70-120	12
1/4-1/2	3/32-5/32	3/32 or 1/8	100-150	12

Use 2% thoriated tungsten (EWTh-2) electrodes. Grind the tip to a 60° angle with a small flat at the tip. Adjust the art on clean scrap metal (not on scaled, hot rolled steel). Argon shielding gas at 15-30 ft^3/hr. Gas cups should be as large as feasible, 1/2" or greater, with a gas lens (diffusing screen) to reduce turbulence.

Gas Metal Arc, RA333 Filler Wire Short-Circuiting Arc Transfer

Wire dia. inch (mm)	Amperes	Volts
0.035 (0.89)	75-120	18-20
0.045 (1.14)	100-140	20-22

Wire stickout about 1/4 inch (6.35mm). Shielding gas flow 25-45 ft^3/hr. A mixture of 90% helium, 7-1/2% argon, 2-1/2% carbon dioxide has produced excellent results.

75% argon, 25% helium may also be used, with shielding gas flow at the upper end of the range. Grinding may be necessary to avoid cold laps at starts and stops.

Globular Transfer

Wire dia. inch (mm)	Amperes	Volts
0.045 (1.14)	165-180	17.9-18.5

Shielding gas argon or argon-helium. Useful for welding heavy plate, where lower heat input is desirable to minimize fissuring.

Pulsed-Arc Transfer

Wire dia. inch (mm)	Amperes	Volts
0.45 (1.14)	150-165	20-21

Shielding gas: 75% argon, 25% helium, 120 pulse/second.

Spray-Art Transfer

Wire Dia. inch (mm)	Amperes	Volts
0.035 (0.89)	160	28
0.045 (1.14)	190	28
0.062 (1.57)	260	30

Shielding gas 99.996% argon. Do not add oxygen.

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Forming

RA333 is normally bent, spun and formed at room temperature. Heating to bend should be avoided. Most nickel alloys suffer loss of ductility, and are likely to tear if formed in the 1200-1600°F range.

Plate bend ductility is strongly affected by edge preparation. Deburring is the minimum acceptable treatment for sheared plate 1/4" and thicker. Band sawed or abrasive cut edges work best. Sheared edges should be ground in the region to be bent.

Bend radius should be at least equal to the thickness of the plate. Nickel alloys cannot be reliably bent over a sharp male die without cracking.

Warm working offers little advantage for most operations. Preheating above 1000°F may approach the low ductility temperature range and cause more harm than good. Heating RA333 to 1000°F does reduce the yield strength by about 30%. This may facilitate the dishing and flanging operations involved in forming heads.

Hot forging should be started at 2200°F. It is important to heat the metal to 2200°F throughout its thickness, as a cool center may tear. Hot working should be finished at no lower than 1800°F.

Top:

As-sheared, burr up. Cracked at 40° bend angle.

Middle:

Shear burr removed. Bent 90° before cracking.

Bottom:

Sheared edge ground. Bent 180° flat on itself, no cracks.

All samples were cut from the same piece of RA333 1/2" plate.

Machining

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RA333 requires low cutting speeds, roughly 25% of those for AISI B1112 steel, and heavy feeds. Set up should be rigid, tools ground and stoned sharp.

The suggested cutting fluid is a sulpho-chlorinated petroleum oil containing active sulfur and about 8-10% fatty oil. It may be blended with equal amounts of paraffin oil. Water soluble oils or chemical emulsions are also used, particularly with carbide tools. All traces of cutting fluid must be removed prior to welding, annealing or use in high temperature service.

Suggested Speeds and Feeds

Operation	Tool Material	Speed SFPM	Feed, inch per rev. rough	finish	Depth of cut, inch rough	finish		
Turning,	M42, M47	20-25						
single point			.010	.007	.100	.025		
and box tools	C2, C3	70-90						
	carbide							
Drilling	M42	20	.002-.004, drill					
			dia. 1/8 - 3/4 inch					
	M1,							
Tapping	M7, M10	10	—	—	—	—		
Broaching	M42	8	chip load .002 inches per tooth					
			Feed, inches per tooth				Depth of cut	
			Cutter diameter, inches					
End			1/4	1/2	3/4	1-2		
Milling	M42	15	.002	.002	.003	.004	.050	
-peripheral	C2	60	.001	.002	.003	.004		
	carbide							
			Feed, inches per revolution					
	M42	20	Reamer diameter, inches					
Reaming			1/8	1/4	1/2	1	1-1/2	2
	C2	60	.002	.006	.008	.010	.012	.014
	carbide							
	M2,	—	Speed, surface feet per minute:					
Die	M7,	—	4-6	5-8	6-10	8-12		
Threading	M10	—	Threads per inch:					
			7 or less	8-15	16-24	25 and up		

Heat Treatment

Most RA333 fabrications are not heat treated after forming or welding. If a full anneal is desired, heat 2000-2150°F (aim 2000-2050°F for sheet gauges), rapid air cool or water quench. Residual stresses and some of the work hardening from severe forming operations may be relieved by heating 1850-1900°F, one hour per inch of thickness, air cool.

RA333 is a fully austenitic material and cannot be hardened or strengthened by heat treatment.

Effect of Annealing Temperature On Hardness of Cold Rolled RA333[12]

Annealing Temp. °F (°C)		Hardness at Indicated % Cold Reduction, Rockwell B 0	10	20		40		60	
As Rolled		94	105	108	(RC 31)	111	(RC 38)	112	(RC 40)
1400	(760)	—	102	106	(RC 29)	111	(RC 37)	113	(RC 40)
1500	(816)	—	102	103		111	(RC 37)	109	(RC 35)
1600	(871)	—	101	102		99		101	
1700	(926)	—	94	93		98		98	
1800	(981)	—	93	93		98		98	
1900	(1036)	—	90	90		95		96	
2000	(1149)	—	89	90		90		90	

Physical Properties

Density[1]

0.294 lb/cu.in.
8140 kg/m^3

Melting Range [1,2]

2375-2450°F
1300-1345°C

Permeability, at H-200 oersted, room temperature

μ = 1.004 annealed
1.006 cold rolled 20%
1.01 cold rolled 50%

Cryogenic Permeability[3]

100-200K (-280 to -100°F) μ = 1.01, measured with an AC technique, field strength 0.1 oersted at 10Hz.

RA333 is a spin glass with spin-freezing temperature of about 8.5K (-444.4°F)

Specific Heat[1]

Temperature °F	(°C)	Btu/lb°F	J/kg•K
100	(38)	0.072	300
300	(149)	0.081	340
500	(260)	0.090	380
700	(371)	0.100	420
900	(482)	0.108	450
1100	(593)	0.118	490
1300	(704)	0.126	530
1500	(816)	0.136	570
1700	(927)	0.145	610
1900	(1036)	0.154	650
2000	(1093)	0.159	670

Thermal Conductivity[4]

Temperature °F	(°C)	Btu•ft/ft^2•hour °F	W/m•K
77	(25)	6.41	11.1
200	(93)	7.02	12.1
400	(204)	8.06	13.9
600	(315)	9.13	15.8
800	(426)	10.2	17.6
1000	(538)	11.3	19.5
1200	(648)	12.4	21.4
1400	(760)	13.5	23.3
1600	(871)	14.5	25.1
1800	(981)	15.6	27.0
2000	(1093)	16.7	28.9

Electrical Resistivity[4,5]

Temperature °F	(°C)	ohm•circ mil/ft	microhm•m
75	(25)	688	1.144
400	(204)	716	1.190
600	(315)	729	1.212
800	(426)	740	1.230
1000	(538)	749	1.245
1200	(648)	755	1.255
1400	(760)	760	1.264
1600	(871)	765	1.271
1800	(981)	769	1.278

Mean Coefficient of Thermal Expansion[6]

Temperature Range °F	(°C)	in/in °F x 10^{-6}	m/m•K x 10^{-6}
70-200	(21-93)	7.0	12.6
70-500	(21-260)	8.0	14.4
70-1000	(21-538)	8.6	15.5
70-1200	(21-648)	9.0	16.3
70-1400	(21-760)	9.3	16.7
70-1500	(21-816)	9.3	16.8
70-1600	(21-871)	9.4	16.9
70-1700	(21-926)	9.5	17.2
70-1800	(21-981)	9.7	17.5

Mechanical Properties

Elastic Properties

Poisson's Ratio, Room Temperature
0.315

Temperature °F	(°C)	Dynamic Modulus of Elasticity[7] psi x 10^6	(MPa)
77	(25)	29.2	(201,000)
200	(93)	28.9	(199,000)
400	(204)	28.1	(194,000)
600	(316)	27.0	(186,000)
800	(427)	25.8	(178,000)
1000	(538)	24.6	(170,000)
1200	(649)	23.4	(161,000)
1400	(760)	22.1	(152,000)
1600	(871)	20.2	(139,000)
1800	(982)	18.2	(125,000)

Mechanical Properties

Minimum Specified Tensile Properties, Room Temperature

Tensile Strength psi (MPa)	80,000 (551)
0.2% Yield Strength psi (MPa)	35,000 (241)
Elongation in 2" (50mm) or 4D, %	30
Hardness, Rockwell B	95 max.

Typical Range of Properties, Room Temperature

Tensile Strength psi (MPa)	90,000-120,000 (620-827)
0.2% Yield Strength psi (MPa)	39,000-70,000 (269-483)
Elongation in 2" (50mm) or 4D, %	31-65
Hardness, Rockwell B	76-95

Charpy V-notch Impact Strength, bar, 91-133 ft-lb (123-180 joule)

Erichsen Cup Depth 9.8-11.0 mm
(0.025 to 0.032" sheet, average of 9 tests)

Cryogenic Tensile Properties

Temperature °F (°C)	75 (24)	-50 (-46)	-100 (-73)	-150 (-101)	-230 (-196)
Tensile Strength psi	93,100	112,000	120,500	124,000	154,000
(MPa)	(642)	(772)	(831)	(855)	(1062)
0.2% Yield Strength psi	46,800	56,400	58,000	64,000	82,400
(MPa)	(323)	(389)	(400)	(441)	(568)
Elongation in 2" (50mm) or 4D, %	46.5	51.5	49	51	47

RA333 Average Elevated Temperature Compressive Strength[8,9]

Test Temperature °F	(°C)	0.2% Offset Yield Strength psi	(MPa)
1400	(760)	31,600	(218)
1500	(816)	25,600	(177)
1600	(871)	26,600	(183)
1700	(927)	19,700	(136)
1800	(982)	14,300	(98.6)
1900	(1038)	10,700	(73.8)
2100	(1149)	3,800	(26.2)

Average Short-time Tensile Properties

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RT to 2200 °F (1204 °C)

Temperature °F	(°C)	Tensile Strength, psi (MPa)	0.2% Yield Strength psi (MPa)	Elongation in 2" (50 mm) or 4D, %	Reduction of Area %
75	(24)	107,000 (738)	47,000 (324)	48	62
200	(93)	100,200 (691)	41,600 (287)	48	55
300*	(149)	96,400 (665)	39,500 (272)	46	54
400	(204)	96,100 (663)	37,000 (255)	49	59
500*	(260)	91,800 (633)	34,800 (240)	47	52
600	(316)	92,500 (638)	32,500 (224)	54	60
700*	(371)	89,500 (617)	33,500 (231)	51	48
800	(427)	89,900 (620)	31,500 (217)	55	57
900*	(482)	86,700 (598)	30,700 (212)	52	47
1000	(538)	85,400 (589)	30,800(212)	53	56
1100	(593)	79,600 (549)	29,300 (202)	49	47
1200	(649)	73,600 (507)	30,700 (212)	43	41
1300*	(704)	61,500 (424)	27,200 (188)	42	41
1400	(760)	53,900 (372)	28,900 (199)	62	50
1500+a	(816)	40,700 (281)	30,400 (210)	94	71
1500*b	(816)	41,600 (287)	30,500 (210)	24	--
1600	(871)	27,500 (190)	23,900 (165)	75	74
1800	(982)	15,700 (108)	12,100 (83.4)	64	69
2000+b	(1093)	7,400 (51.0)	6,500 (44.8)	25	--
2100*b.	(1149)	6,600 (45.5)	5,000 (34.5)	36	--
2200*b	(1204)	4,000 (27.6)	3,500 (24.1)	106	71

* average of 3 tests
\+ average of 2 tests
a bar only
b sheet only

Effect of Elevated Temperature Exposure On and Short-time Elevated Temperature Properties of Mill Annealed Plate and Bar[1,10]

Test Temp. °F	(°C)	Aging Temp. °F	(°C)	Aging Time hours	Ultimate Tensile psi	(MPa)	0.2% Offset Yield Strength psi	(MPa)	Elongation %	Red. of Area %	Hardness Rockwell B	Charpy V-notch Impact Energy ft-lb (J)	Charpy V-notch Lateral Expansion inch (mm)
80	(27)	none		--	104,500	(721)	45,600	(314)	50	59	84	43.3 (58.7)	0.040 (1.0)
80	(27)	1200	(649)	1000	110,000	(785)	52,200	(360)	36	34	--	19.5 (26.4)	0.019 (0.48)
80	(27)	1400	(760)	1000	106,700	(736)	46,000	(317)	27	27	89	--	--
80	(27)	1400	(760)	1000	105,400	(727)	50,700	(350)	11	10	96	--	--
80	(27)	1500	(816)	1000	109,300	(754)	52,600	(363)	20	16	--	7.5 (10.2)	0.005 (0.13)
80	(27)	1800	(982)	1000	94,900	(654)	38,000	(262)	34	26	--	47.8 (64.8)	0.037 (0.94)
1200	(649)	1200	(649)	1000	77,000	(531)	34,400	(237)	43	47	--	--	--
1500	(816)	1500	(816)	1000	40,800	(281)	25,800	(178)	73	72	--	--	--
1800	(982)	1800	(982)	1000	14,200	(97.9)	11,300	(77.9)	90	83	--	--	--
1800	(982)	none		--	15,600	(107.6)	10,300	(71.0)	89	78	--	--	--

Data are average values of from two to nine tests.

Effect of Annealing Treatment on Tensile Properties of Aged RA333[11]

Condition	Ultimate Strength psi	(MPa)	0.2% Offset Yield Strength psi	(MPa)	Elongation %	Reduction of Area, %
Annealed	102,700	(708)	42,400	(292)	51.0	53.2
Annealed + aged	114,800	(792)	58,600	(404)	5.0	4.7
Annealed + aged + 1800°F 1 hr.	112,700	(777)	45,200	(312)	35.5	35.7
Annealed + aged + 1800°F 2 hr.	109,300	(754)	43,600	(301)	41.0	47.9
Annealed + aged + 1800°F 4 hr.	108,700	(749)	42,500	(293)	42.0	48.5
Annealed + aged + 1900°F 1 hr.	105,800	(729)	43,400	(299)	43.5	48.8
Annealed + aged + 1900°F 2 hr.	106,100	(732)	42,400	(292)	43.0	48.3
Annealed + aged + 1950°F 15 min.	105,600	(728)	43,800	(302)	47.0	51.6

Material annealed 2050°F, (1120°C) air cool. Aging performed for 1000 hours at 1400°F (760°C). Bar stock from heat 2888, chemistry:

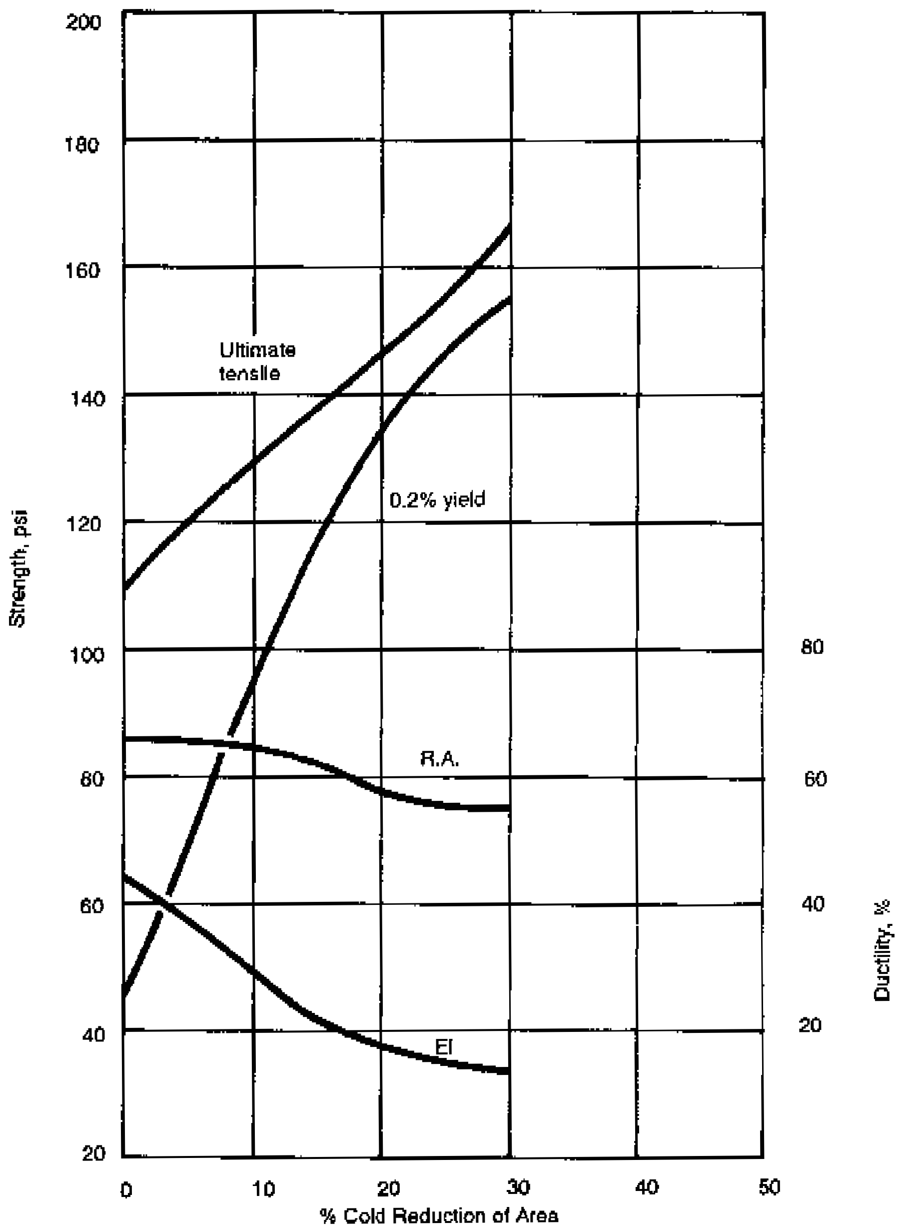
C	Mn	P	S	Si	Ni	Cr	Mo	Co	W
.042	1.67	.015	.007	1.40	45.21	25.96	2.90	3.17	3.06

Effect of Elevated Temperature Exposure OnShort-time Properties of Shielded Metal Arc Weldment[1]

Test Temperature °F	(°C)	Aging Temperature 1000 hour exposure °F	(°C)	Ultimate Tensile Strength psi (MPa)	0.2% Offset Yield Strength psi (MPa)	Elon- gation %	Red. of Area %	Tensile Failure Location B=Base metal W=weld metal	Charpy V-Notch Impact Energy ft-lb (J)	Lateral Expansion inch (mm)
80	(27)	none		110,200 (760)	54,800 (378)	33.3	44.1	B	63.2(85.7)	0.051 (1.3)
80	(27)	1200	(649)	111,600 (769)	59,800 (412)	25.8	34.2	B	26.0(35.2)	0.019 (0.48)
80	(27)	1500	(816)	109,000 (748)	58,100 (401)	8.0	9.4	W	4.2(5.7)	0.002 (0.05)
80	(27)	1800	(982)	72,400 (499)	39,400 (272)	7.6	10.4	W	14.2(19.3)	0.016 (0.41)
1200	(649)	1200	(649)	80,200 (553)	39,800 (274)	30.7	39.4	B	--	--
1500	(816)	1500	(816)	46,500 (321)	26,200 (181)	50.9	63.4	B	--	--
1800	(982)	1800	(982)	15,100 (104)	14,300 (98.6)	64.6	84.0	B	--	--
1800	(982)	none		16,200 (112)	10,900 (75.2)	50.4	78.9	B	--	--

Charpy and unexposed room temperature data average of three tests, balance of tensile data average of two tests. Weldment in center of tensile gauge length. Charpy notch in weldment, parallel to weldment centerline. All specimens from 1” (25.4mm) plate, double V weld joint preparation.

Starting material hot rolled 3/4” dia. bar, annealed 2050°F, water quench. Heat 38253.

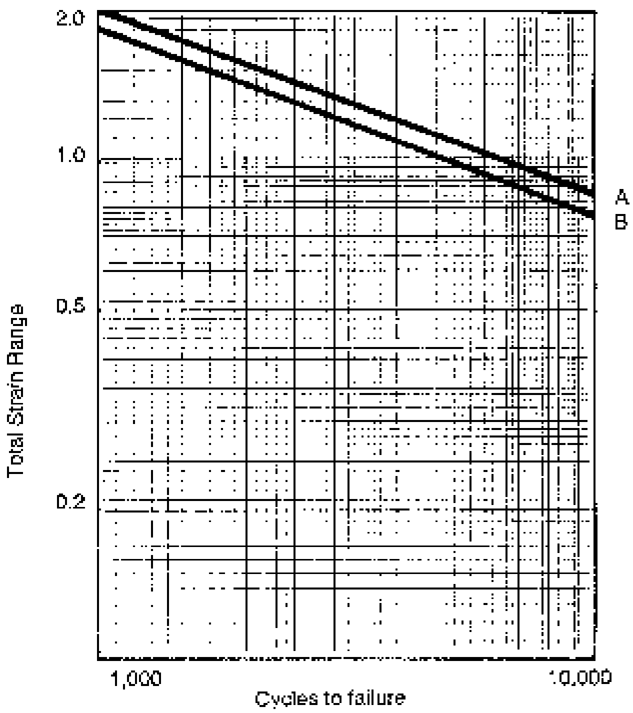


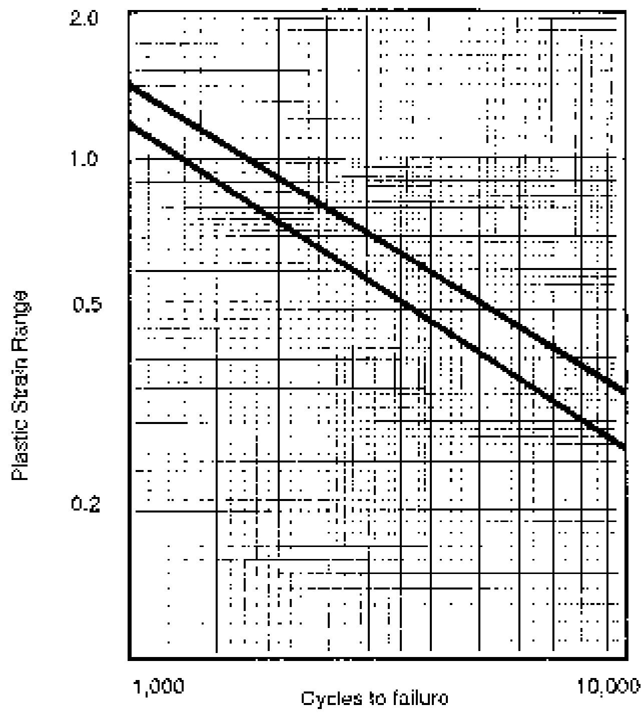
Effect of Temperature on Tensile Properties of 20% Cold Drawn Bar

Test Temp °F (°C)	Tensile Strength psi (MPa)	0.2% Offset Yield Strength psi (MPa)	Elongation in 4D %	Reduction of Area %
75 (24)	147,050 (1014)	134,450 (927)	17.8	57.4
450 (232)	129,650 (894)	125,450 (865)	15.2	54.4

Low Cycle Fatigue
Room Temperature

RA333®





A, C As mill annealed 2050°F (1120°C), fan cool, grain size ASTM 6.5 and laboratory solution annealed 2200°F (1204°C) in argon, warm (60°C) water quench, grain size ASTM 3.0

B, D Solution annealed plus 1350°F (732°C) 16 hour age.

All tests at room temperature on Instron fatigue tester [13]

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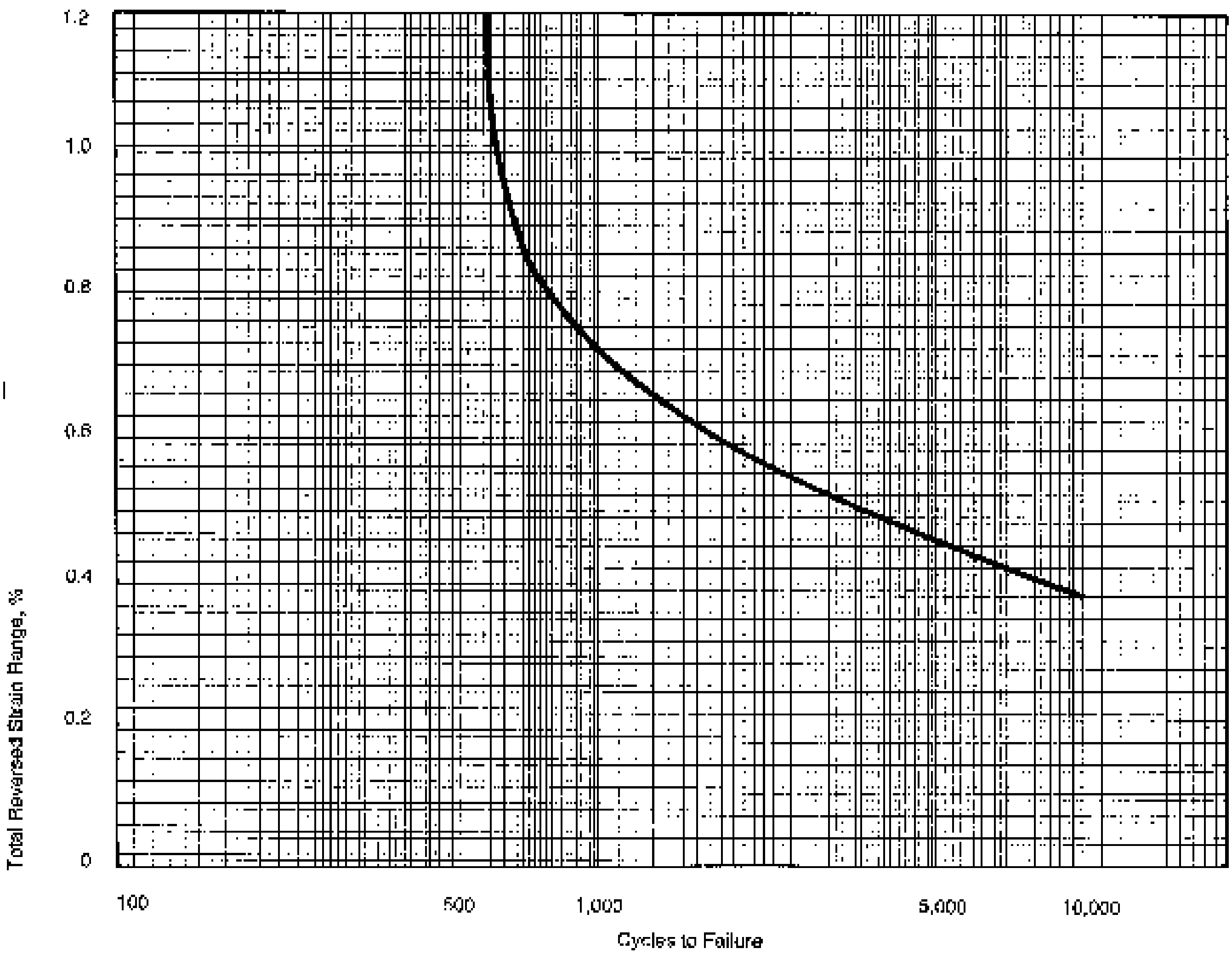
Low Cycle Fatigue Elevated Temperature



1600°F, 16 cycles per minute.

Material tested: 3/4” dia. hot rolled annealed bar, heat 38314.

C	Mn	Si	Ni	Cr	Mo	Co	W
.066	1.68	1.00	44.91	24.65	2.86	2.77	2.51

Low Cycle Fatigue and Creep Strength

Low Cycle Fatigue

RA333 shaker hearth, one of twin hearths in a Surface Combustion furnace. Temperature 1600-1650°F (870-900°C), enriched endothermic atmosphere used for bright hardening and light carbonitriding.

In service, the cyclic strains are rarely well defined. This shaker hearth furnace moves the work pieces along by a reciprocating motion of the hearth. Failure is usually combined mechanical fatigue and thermal strain at the charge (cooler) end. This particular design in 3/8" (9.5mm) RA333 plate lasted 22 months (or 16,000 cycles). Previous cast 66% Ni, 17% Cr hearths gave erratic life ranging upwards from 3 months.

Creep Strength

Average Stress, psi (MPa) for:

Temperature		Secondary Creep Rate of		Total Creep in 10,000 hours, %			
°F	(°C)	0.00001%/hr	0.0001%/hr	0.5	1.0	2.0	5.0
1100	(593)	--	22,000 (152)	19,000	19,500	20,500	22,000
				(131)	(134)	(141)	(152)
1200	(649)	6800 (46.9)	9,800 (67.6)	--	--	--	--
1300	(704)	5400 (37.2)	7,700 (53.1)	--	--	--	--
1400	(760)	4600 (31.7)	6,400 (44.1)	4,000	5,300	6,500	8,350
				(27.6)	(36.5)	(44.8)	(57.6)
1500	(816)	2900 (20.0)	4,200 (29.0)	--	--	--	--
1600	(871)	1900 (13.1)	2,700 (19.0)	2,350	2,450	2,800	2,950
				(16.2)	(16.9)	(19.3)	(20.3)
1700	(927)	1100 (7.58)	1,650 (11.4)	--	--	--	--
1800	(982)	560 (3.86)	880 (6.07)	700	770	820	850
				(4.83)	(5.31)	(5.65)	(5.86)

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Rupture Strength

Average Stress, psi (Mpa), to Rupture for Indicated Time, Mill Annealed

Temperature °F	(°C)	100 hr	1000 hr	10,000 hr	100,000 hr (extrapolated)
1100	(593) +	46000 (317)	34000 (235)	25000 (170)	--
1200	(649)	33500 (231)	23500 (162)	16500 (114)	11500 (79.3)
1300	(704) *	24000 (165)	17000 (117)	12000 (82.7)	8400 (57.9)
1400	(760)	18500 (128)	13000 (89.6)	9200 (63.4)	6500 (44.8)
1500	(816)	13000 (89.6)	8600 (99.3)	5700 (39.3)	3700 (25.5)
1600	(871)	8400 (57.9)	5100 (35.2)	3100 (21.4)	1900 (13.1)
1700	(927) *	5600 (38.6)	3200 (22.1)	1800 (12.4)	1050 (7.24)
1800	(982)	3600 (24.8)	1950 (13.4)	1050 (7.24)	580 (4.0)
1900	(1038) *	2300 (15.9)	1200 (8.27)	630 (4.34)	330 (2.28)
2000	(1093)	1500 (10.3)	720 (4.96)	360 (2.48)	--
2200	(1204) +	640 (4.41)	300 (2.07)	140 (0.96)	--

+ Single heat data

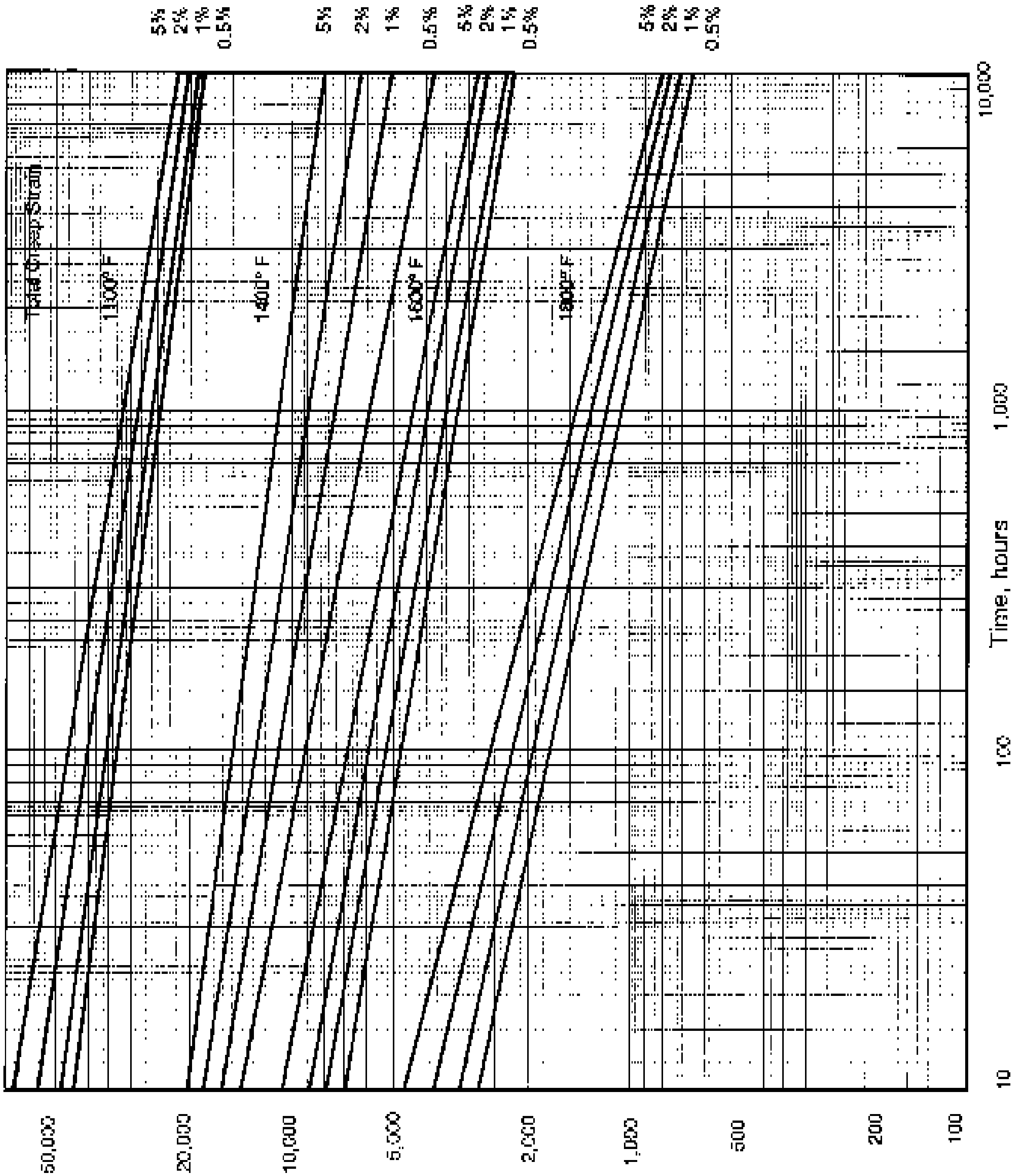
* Interpolated by Larson-Miller technique
  $T (C + \log t)$ = Parameter, using C=15.65

These creep and rupture data represent the average of tests run on bar and plate for times up to about 10,000 hours. The data are not the minimum properties at temperature. Actual design stresses must include a factor of safety, and take into account the effects of thermal cycling, stress concentrations, thermal gradients and the corrosive environment.

We offer for your consideration two different philosophies of setting maximum allowable design stress:

1. Industrial furnace components are often designed to 50% of the stress for either 10,000 hour rupture, or 1% in 10,000 hour minimum creep rate.

2. Pressure vessels, where failure may entail danger or very high cost, are usually designed to 67% of the extrapolated 100,000 hour rupture strength.



5%
2%
1%
0.5%
Total Creep Strain
1400° F
1600° F
Time, hours
10
100
1,000
10,000
50,000
20,000
10,000
5,000
2,000
1,000
500
200
100

RA333®

Minimum Creep Rate

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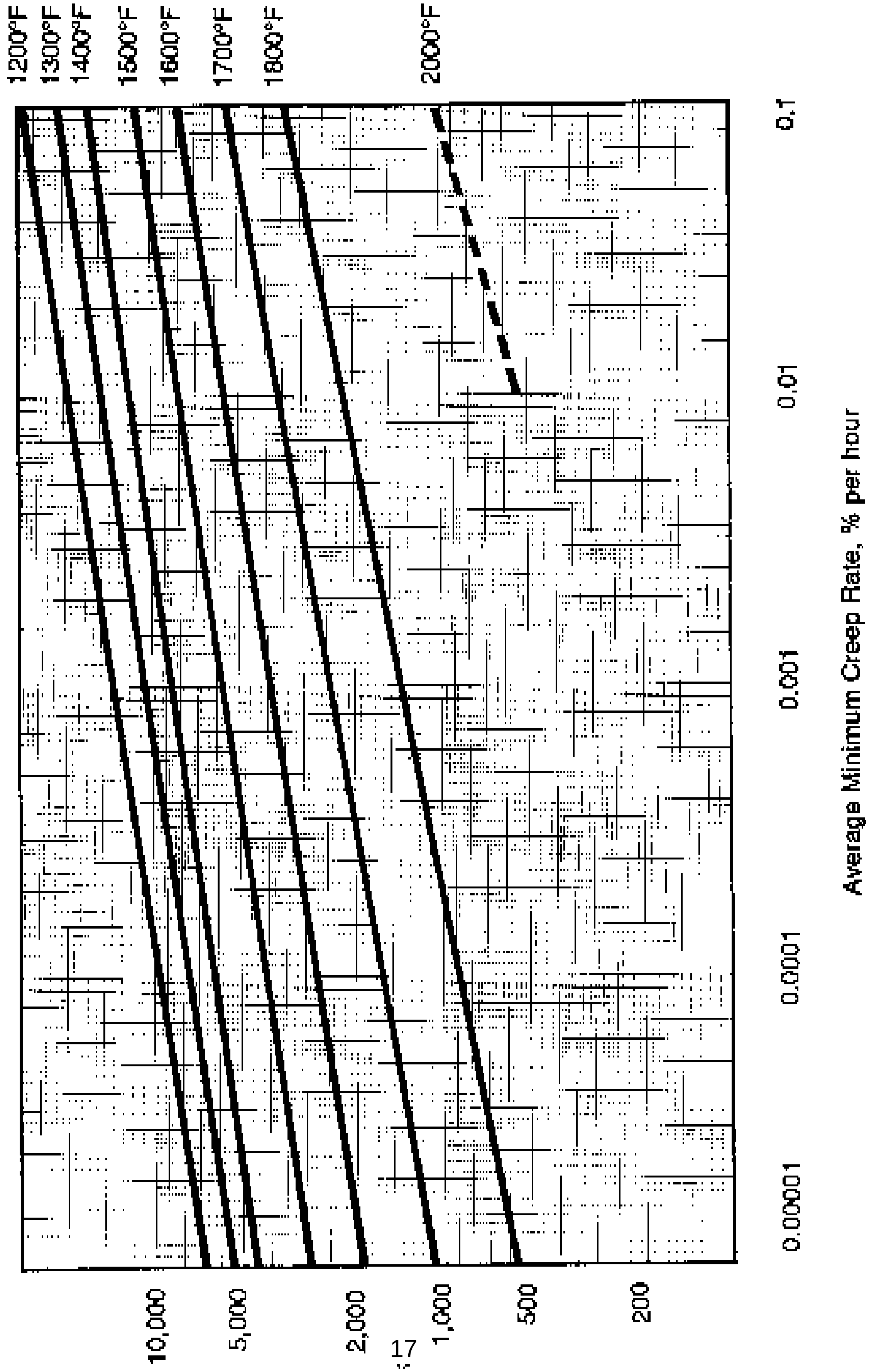
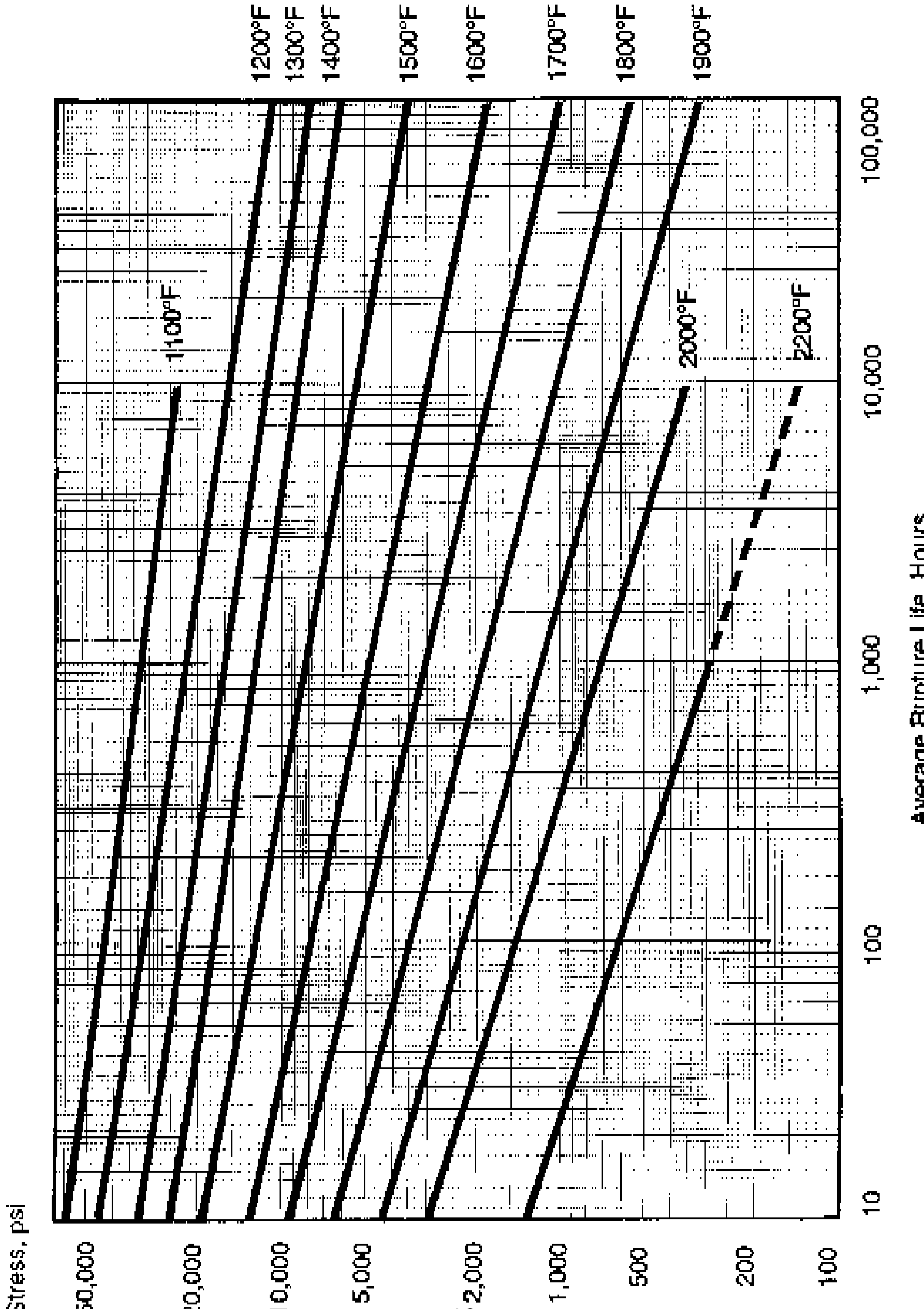
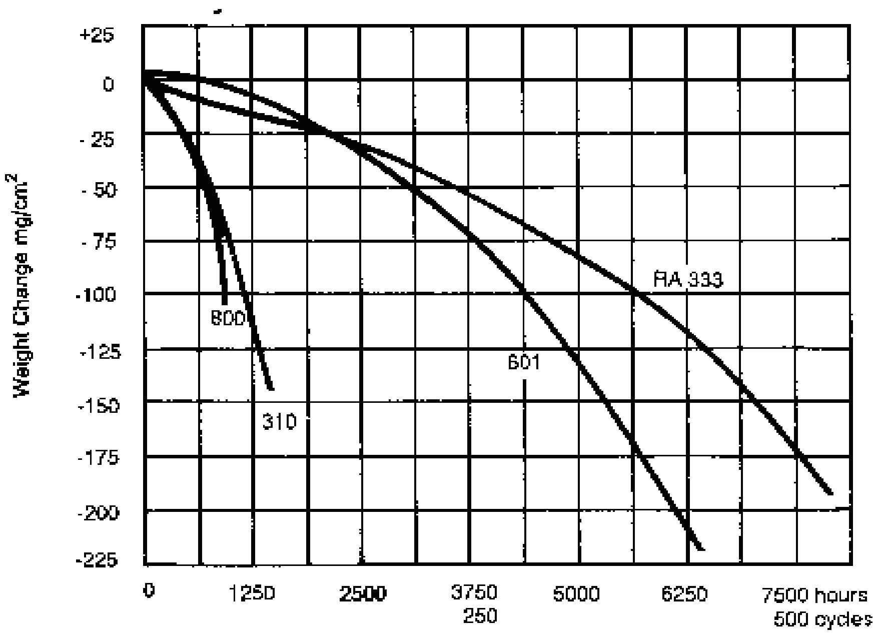


Rupture Strength



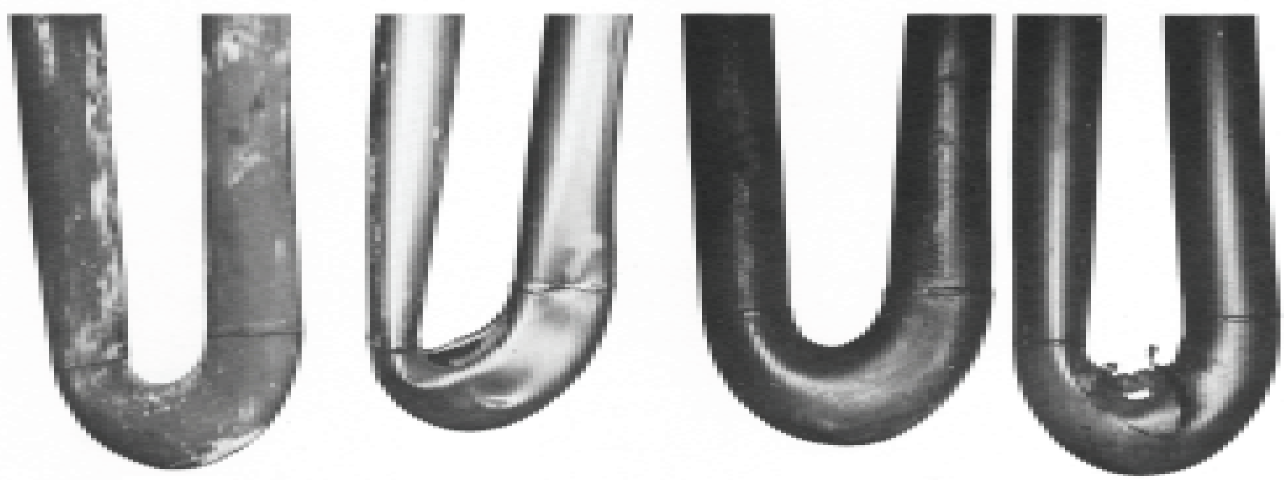
RA333 has excellent oxidation resistance through 2200°F (1200°C). This is demonstrated by numerous test programs. Actual high temperature service performance confirms these laboratory results.

Valid comparison of the more oxidation resistant alloys may require testing for several thousand hours. This cyclic test shows relative alloy behavior after test times which approximate the expected service life of many components [14]



Cyclic oxidation resistance of high-temperature alloys at 1900°F (1038°C)

The performance of these .120” (3mm) radiant tubes, operating under highly cyclic conditions over 1900°F (1038°C), compares reasonably with shorter time cyclic oxidation tests at 2100°F (1150°C)

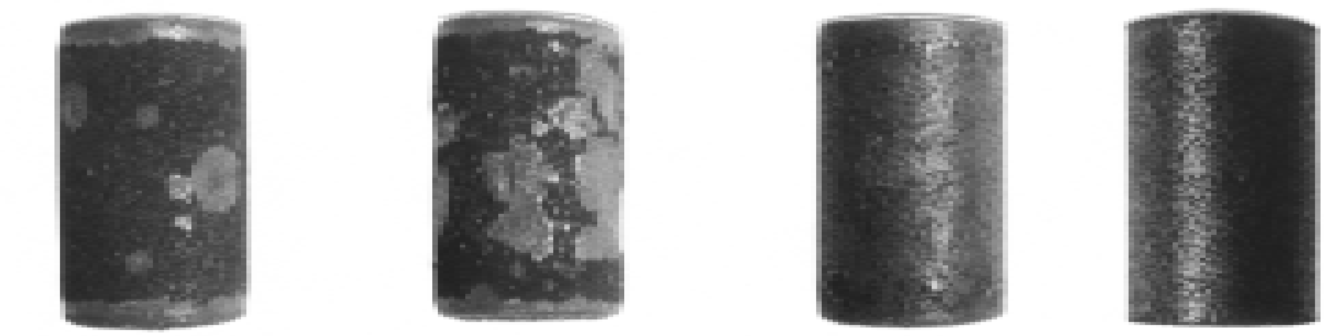


RA333 RA310 RA330 RA309

(RA309 and RA310 tubes burned out in service. RA333 still in excellent condition.)

Oxidation

2100°F Oxidation Test Specimens, 2X



RA309 (440 hr) High weight gain, local scale breakdown

RA310 (500 hr) Low weight gain, local scale breakdown

RA330 (240 hr) Moderate weight gain, uniform scaling

RA333 (400 hr) Low weight gain, uniform adherent scale

Total weight gain, mg/cm^2, 20 hour cycles in air at 2100°F (1150°C)

Alloy	100 hours	300 hours	400 hours
RA333	3.8	6.8	8.3
601	4.6	7.8	8.9
RA310	5.91	10.1	13.2
RA446	8.09	23.4	29.7
RA330	6.4	15.2	28
RA309	5.7	12.1	40
800	17.4	80.7	109

(RA330 showed rather large weight gain but oxidation was uniform, without the local scale breakdown of RA309 and RA310.)

Dynamometer Tests

Engine dynamometer tests of alloy rings in insulated exhaust pipes, leaded fuel 1800-1900°F (980-1400°C) showed the following weight change, mg/cm^2, after 1000 hours:[14]

RA333	-0.34	RA330	-7.67
18SR™	-2.09	800	-20.0
601	4.36 *	310	-48.7

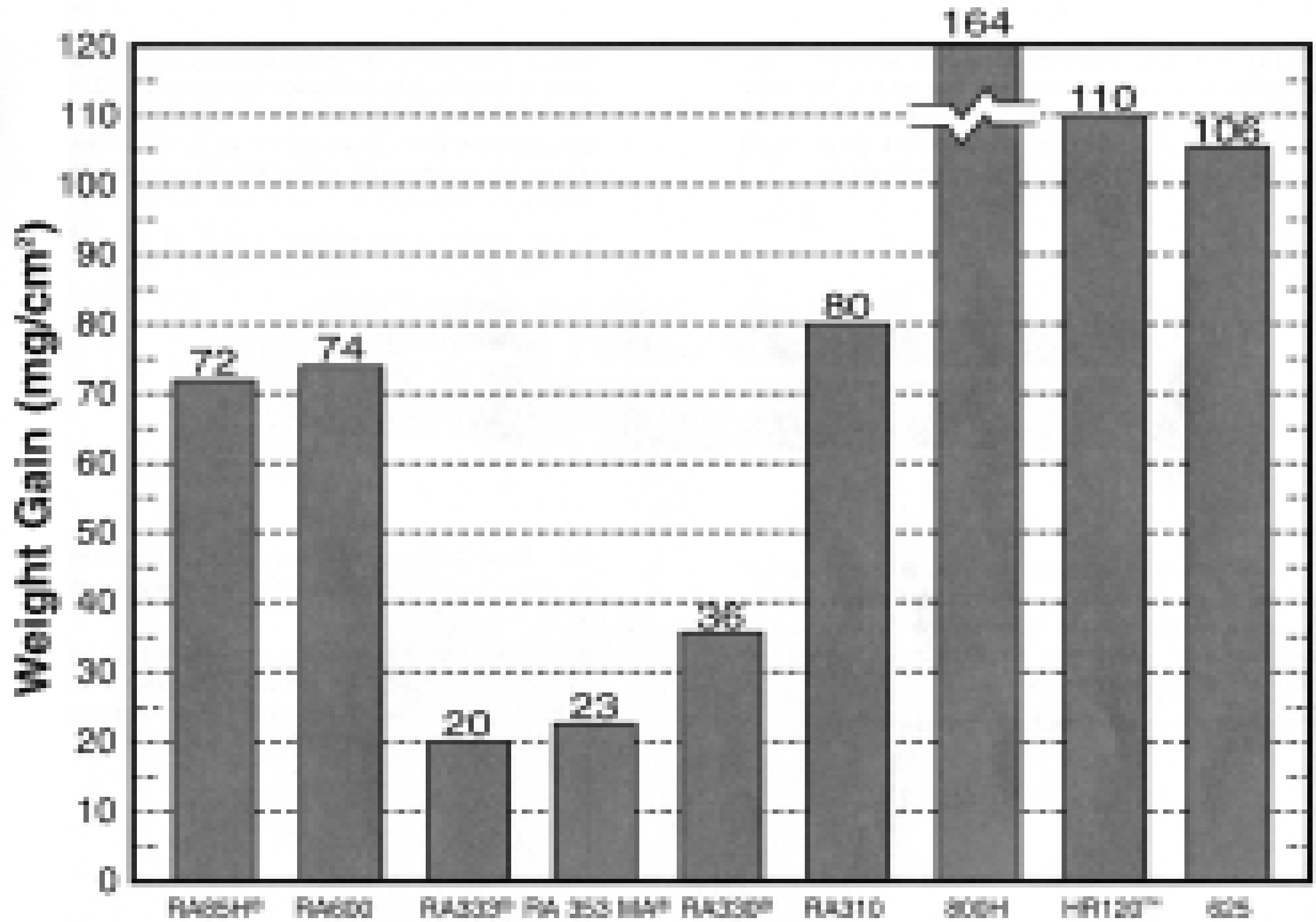
* 700 hour test

Activation Energy

The activation energy for parabolic oxidation of RA333 has been calculated variously as 38.5 kcal/mole (161 kJ/mole)[15] and 51.1 ± 4.6 kcal/mole (214 19kJ/mole)[16].

Spalled scale from 2100°F (1150°C) cyclic oxidation testing is non-magnetic, with a lattice parameter of 8.40 A. The scale includes the hexagonal oxide $(Cr, Fe)_2O_3$, cubic oxide $(Cr, Fe)_3O_4$ and NiO[17].

Oxidation



2100°F, 1640 hours. Cycled to room temperature weekly.

Metal Dusting

1" Sch 40 oxygen probes inserted through the roof of a surface combustion furnace were examined after more than 25,594 hours (3 years) at temperature. Furnace atmosphere endothermic enriched with 0.7-0.8% methane to a 1.20% carbon potential. Metal dusting is a problem where the pipes pass through the furnace wall, and where temperature is down around 1100°F (600°C).

Alloy	Condition	Results
RA333®	As received	Dark, no pits at 27,594 hours
RA85H®	As received	Black, no pits (at 8122 hours)
RA85H®	Preoxidized	Black, no pits (at 7549 hours)
RA330®	As received	Extensive, deep pitting, almost through pipe wall (at 19,472 hours)
214™	As received	Moderately deep, scattered pits (at 19,472 hours)
HR-120™	As received	Pitted--removed from test (at 11,264 hours)
HR-160	As received	Pitting started at 24,422 hours

Carburization

RA333®

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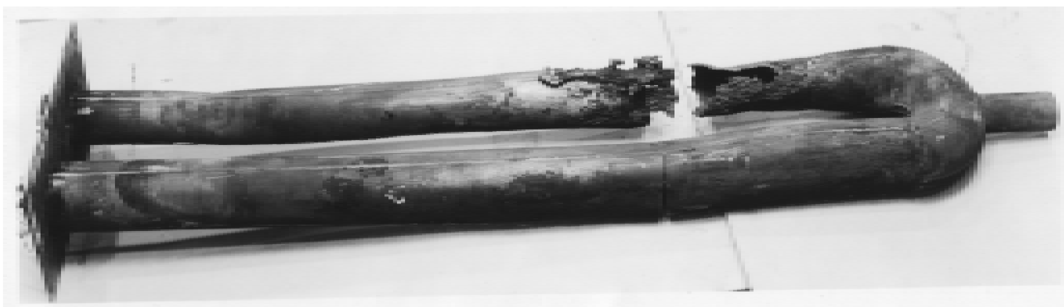
RA333 was originally developed to withstand high temperature carburizing service. It is one of the most carburization resistant materials available. Radiant tubes fabricated of 0.120 inch (3mm) RA333 have given 8 to 10 year life in various industrial carburizing furnaces.

choice of a realistic laboratory carburization test. However, good correlation with service experience is found when the test is conducted for sufficient time. Gas carburizing tests need to be performed for 1000 hours or more. The atmosphere should closely simulate that intended in actual service.

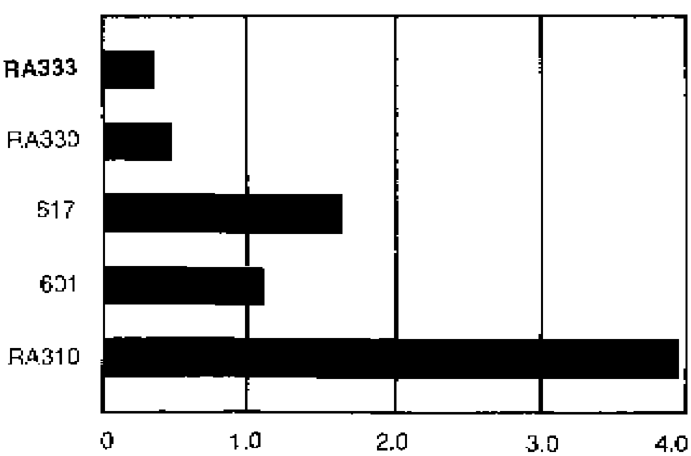


This radiant tube lasted 8-1/2 years in the charge zone of a three row continuous pusher carburizer furnace. Failure was by localized melting, from uncontrolled burning of soot deposits. Eight other RA333 tubes continued in service until the furnaces were sold.

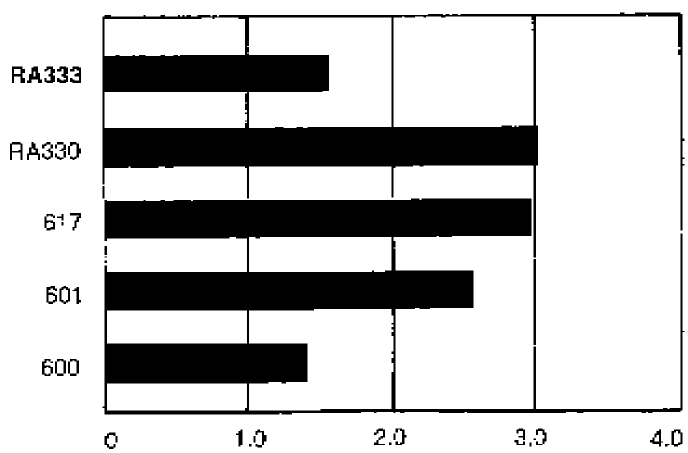
There has been considerable dispute regarding the

The following data were obtained in an electrically heated commercial carburizing furnace at two different temperatures.

In both cases total exposure hours were distributed 20% endothermic + natural gas carbon potential 1.0-1.2% C relative to iron, 70% nitrogen, and 10% air burnout cycle at 100°F reduced temperature.



Weight % Carbon, 0.020" Surface Cut 1750°F (954°C)
4300 Hour Exposure

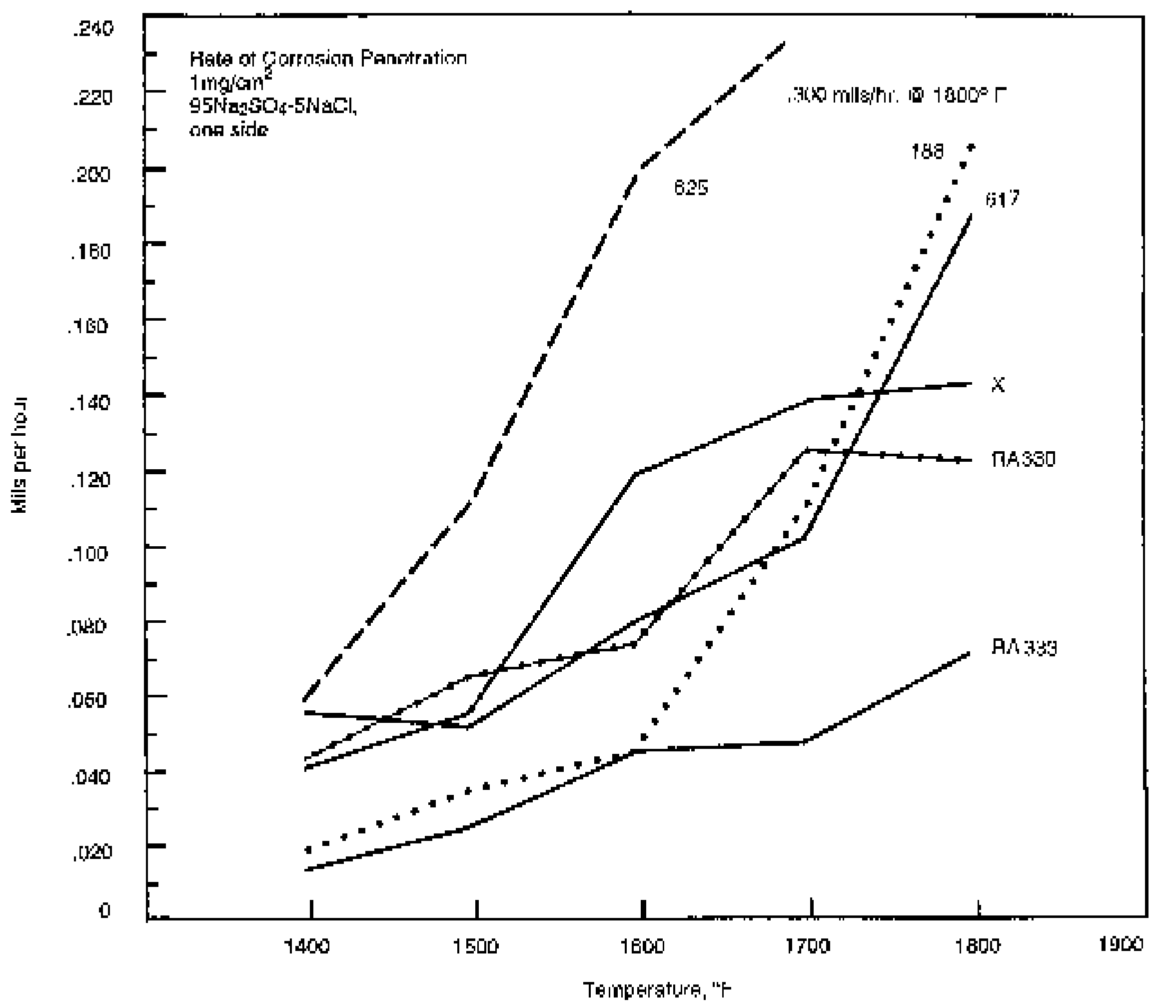


Weight % Carbon, 0.045" Surface Cut 1900°F (1038°C)
2260 Hour Exposure

Hot Corrosion

Hot corrosion in gas turbine engines is the rapid attack by a film of molten salt in an oxidizing atmosphere. Corrosion resistance is strongly dependent upon chromium level. The alloying elements aluminum, vanadium, molybdenum, tungsten and columbium are detrimental to hot salt corrosion resistance. [18,19]

RA333 with its high chromium and moderate level of tungsten and molybdenum, has excellent hot salt corrosion resistance. [20-23]



(after Stetson and Moore)

RA333 combustion cans, scrolls and transition pieces for large land based gas turbine.

Hot Corrosion

Alloy	Time hours	Maximum Penetration mils (mm)
RA333	484	2.1 (0.05)
718	576	1.2 (0.03)
310	576	2.6 (0.07)
446	576	3.1 (0.08)
Hastelloy® S	484	4.1 (0.10)
Nimonic® 263	485	4.1 (0.10)
Haynes® 188	484	6.6 (0.17)
617	484	7.8 (0.20)
430	484	9.1 (0.23)
UmCo-50	576	16.2 (0.41)

Temperature 1175°F (635°C). Specimens sprayed with 1 $PbSO_4$ 15 K_2SO_4 84 Na_2SO_4 (mole%). Atmosphere 0.15% SO_2, 76%O_2, balance N_2, flowing 0.03 cfh (0.85 L/h). From Beltran and Saegusa.[23]

Waste Incinerators

For industrial applications other than gas turbines, the hot corrosion environments are much more complex and not well defined. One of the most severe conditions in which RA333 has been tested is in shipboard waste incinerators. These handle a mixture of seawater, garbage, sewage, and waste oil at temperature of 1400°F (760°C) and higher. Some 500 hour test results are:[24]

Average Corrosion Rate

Alloy	mil/year	mdd	Remarks
690	2.8	16	very light scaling
Haynes 150	7.5	42	very light scaling
310	13.0	72	light scaling
446	24.3	126	moderate scaling
309	25.3	139	light scaling
RA333	41.8	239	moderate scaling
Haynes 188	46.6	296	moderate scaling
Hastelloy X	249	1420	heavy scaling
617	234	1360	heavy scaling
601	382	2130	heavy scaling (fell apart)
RA330	684	3800	completely corroded (no metal left)
Hastelloy S	1045	6350	completely corroded (no metal left)

Results of relatively short time tests such as above must be interpreted with caution. Because alloys may enter a breakaway[25] corrosion mode, corrosion rates cannot be extrapolated to long times.

Aluminum Brazing

RA333 fixtures resist attack by the fluorides involved in aluminum salt bath brazing. The results of one service test at 1125°F (607°C) are:

Alloy	Total Life Days
RA333	197 (end of test-- no failure)
600	112
Nickel 200	51
Hastelloy C-276	40
601	14

Other work has shown the 25% Cr ferritic, RA446, to be unsuitable in Al salt bath brazing.

Carbon Electrode Production

RA333 is exceptionally resistant to gaseous corrosive environments under oxidizing conditions. One field test, 2400 hours at 1500-1520°F (815-827°C), showed RA333 superior to a 26%Cr, nickel-free ferritic. The coupons were exposed to combustion products of combined carbon electrode bake oven effluent and residual fuel oil.[26]

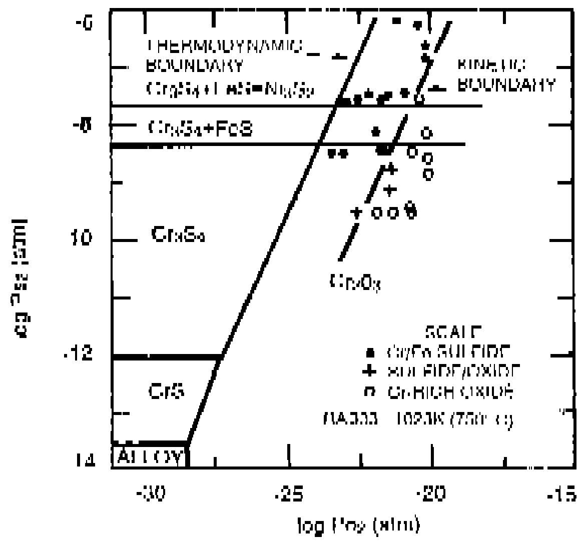
Alloy	Weight Change g/cm^2
RA333	+ 0.02
E-BRITE	+ 0.07
RA330	-21.59
Type 316	-42.04

Hot Corrosion

Sulfur Dioxide

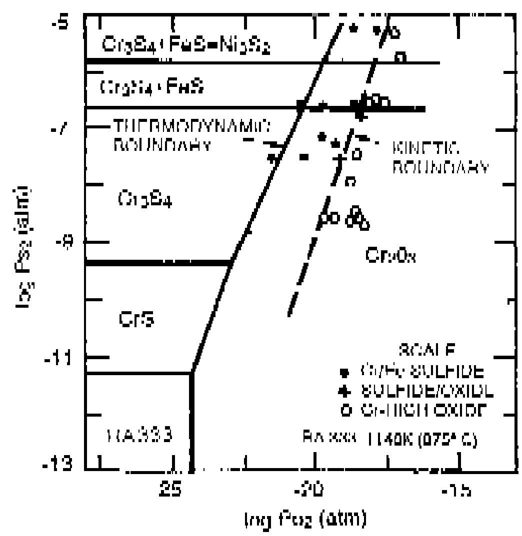
In a high temperature SO_2 environment, RA333 has shown better corrosion resistance than some lower nickel grades. Corrosion was primarily intergranular penetration. The behavior of RA333 reflects its resistance to grain coarsening in service, as well as stability of oxide film.

Alloy	Total Penetration mils/year	Final Grain Size ASTM
RA333	28-47	5
253MA	24-52	4
309	28-136	00
310	66-122	00 to 4-5
RA330	71-155	00



Test Conditions:

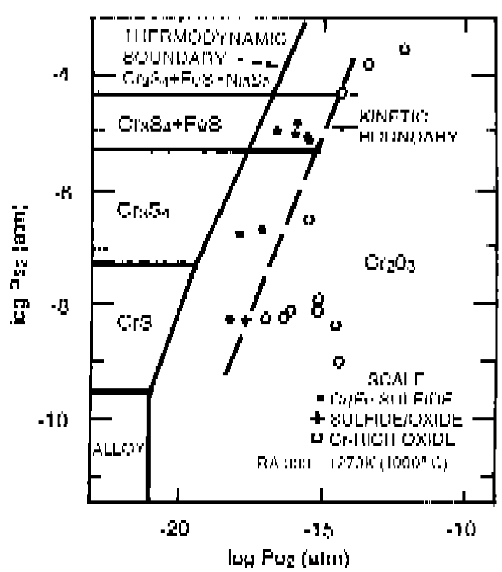
1850°F (1008°C), 1862 hours. Atmosphere 13.6%SO_2, 11.1%CO_2, 20.3%H_20, 53.9%N, 0.5%O_2, 0.6%Ar. Solid particles were 86.6%MgO, 5.4%$CaSO_4$, 2.7%SiO_2, 2.6%$MgSO_3$, 2.6%$MgSO_4$. From Rolled Alloys Investigation 27-84.



Coal Gasification

Although RA333 resists many oxidizing sulfidizing conditions, it is not suggested for strongly reducing sulfur bearing environments. The type of scale, oxide or sulfide, formed on RA333 as a function of oxygen and sulfur partial pressure has been defined by Natesan[27]. Note that to avoid sulfidation requires more oxygen than would be predicted by thermodynamics alone. Specifically, it is necessary to have an oxygen partial pressure about 1000 times the value for the oxide/sulfide thermodynamic phase boundary.

Types of Scale Developed on RA333 as a Function of Oxygen and Sulfur Partial Pressures in the Gas Environment at Temperatures of 750 (fig.1), 875 (fig. 2), and 1000°C (fig. 3). Conversion factor: 1 atm = 0.101356 MPa. ANL Neg. No. 306-79-628.



Summary

RA333 has good resistance to sulfur dioxide in oxidizing products of combustion. It also resists hot salt environments as diverse as those encountered in gas turbines, and in aluminum salt bath brazing. RA333 should be included in test programs involving waste incineration. However, RA333 is not suggested for strongly reducing sulfidizing environments such as in coal gasification or pyrolytic incinerators.

Aqueous Corrosion

RA333 has good aqueous corrosion resistance and is essentially immune to chloride stress corrosion cracking.

RA333 is suggested when the service conditions range from liquid acids to temperatures of 2000°F (1100°C) or higher.

RA333 Sulfuric Acid Corrosion Rates

Mils/Year - H_2SO_4 Concentration

Test Temperature	Air Free					
150°F (65.6°C)	10%	20%	40%	50%	60%	70%
RA333	2.3	2.8	--	--	--	--
176°F (80°C)*						
RA333	2.9	--	5.4	22.4	23.6	26.5
316	151	--	--	--	--	--
625	2.3	--	--	--	--	--
825	4.7	--	--	--	--	--
200°F (93.3°C)						
RA333	19.5	23.0	--	--	--	--

Test Temperature	Aerated								
150°F (65.6°C)	10%	20%	30%	40%	50%	60%	70%	80%	90%
RA333	0.10	0.1	--	--	--	--	--	--	--
176°F (80°C)									
RA333	.6	0.1	41	35	52	42	43	120	44
316	.6	270	284	--	--	--	--	--	--
625	.6	--	--	0.7	42	41	67	--	--
825	.6	16	53	40	22	20	22	11	--
200°F (93.3°C)									
RA333	18.6	29.5	--	--	--	--	--	--	--

Note: The information on these various materials was all developed in the same laboratory in order to provide a direct comparison among alloys in commercially pure sulfuric acid. Corrosion rates shown are valid only for the precise conditions of this test and may not necessarily agree with those determined in other laboratories under nominally similar conditions. Samples about 1/4 x 5/8 x 1" were tasted in 1000ml flasks with 500 ml of solution.

Exposure times ranged from 300 to 400 hours. Acid was not replenished over duration of test.

* Average of five 48 hour periods + average of three 48 hour periods.

Corrosion in 15% H2SO4 plus 15% Oakite® PC-10 inhibitor, 160°F (71°C)

Alloy	Corrosion Rate mils/year	mdd
20Cb-3®	5.00	(28)
600	8.07	(47)
RA333	9.85	(57)
RA330	18.8	(104)
1018 steel	293	(1600)

Application: Baskets to anneal and pickle alloy steel parts.

Source: Rolled Alloys Investigation 12-84.

Hydrochloric Acid Corrosion Rates

mils/year -- HCl concentration

Test Temperature

°F	(°C)	2%	5%	15%	25%	37%
80	(27)	6.6	8.5	6.6	6.4	23
150	(66)	60	196	194	185	361

Simonds Saw and Steel Co. data. RA333 rough forged bar was used at Simonds for pickling racks in 150°F 15% HCl. Service experience was reasonably favorable (as much for ready availability of bar as for its corrosion resistance).

Aqueous Corrosion

RA333 has tolerable resistance to nitric acid as-annealed 2050-2150°F (1120-1180°) for high temperature service. Re-annealing RA333 at 1700°F (930°C) for an hour greatly improves its resistance to boiling nitric acid. This stabilization anneal also prevents the material from sensitizing, as might occur in the HAZ of plate welds.

ASTM A 262 Practice C
(65% boiling nitric acid, average of five 48 hour periods)

Condition	Corrosion rate mils per year	(mdd)
Mill annealed	42	(240)
Mill annealed plus 1700°F (930°C) 1 hour air cool	11.5	(66)
Mill annealed plus sensitize 1250° (677°C) 1 hour	156 (discontinued after three 48 hour periods)	(900)
Mill annealed plus 1700°F (980°C) 1 hour, plus sensitize 1250°F (677°C) 1 hour	11.5	(66)

Adogen® 470 DE Fabric Softener 150°F (66°C)

Alloy	Exposure Time, Days	Corrosion Rate mil/year	mdd
RA333	31	0.056	0.32
20Cb-3®	10-31	0.23	1.3
		(0.16-0.32)	(0.9-1.8)
RA200	31	0.38	2.4
RA400	31	0.61	3.7
RA600	31	0.24	1.4
RA330®	10-31	0.59	3.3
		(0.24-0.96)	(1.3-5.3)

Laboratory corrosion tests run in this product showed RA333 to be superior to various alloys developed specifically for corrosion resistance.

Stress Corrosion Cracking

Results of "U" Bend Stress Corrosion Cracking Test in Boiling 42% Magnesium Chloride

	RA333			
Heat No.	3939	9002	6331	3552
Parent Metal only	P	P	P	P
Parent Metal only	P	P	P	P
Parent Metal with transverse weld	P	P	P	P
Parent Metal with transverse weld	P	P	P	P
Weld Metal only	P	P	P	P

Note: P = no cracks in 300 hours

Polythionic Acid SCC[28]

Specimens 1/8 x 3/8 x 3 inches (3 x 9.5 x 76mm) made into 3/16 inch (4.76 mm) radius U-bends. Sensitization treatments performed 1200°F (649°C) 4 hour air cool. Welds made with RA333-70-16 AC/DC electrodes.

Condition	RA333
mill annealed	passed (160 hours)
mill annealed and sensitized	passed (160 hours)
as welded	passed (160 hours)
welded and sensitized	passed (160 hours)

Stress Corrosion Cracking

Resistance of Duplicate U-Bend Specimens of RA333 to Stress Corrosion Cracking[29] in simulated Deep Sour Gas Solutions Containing 0.8 MPa (100 psi) H_2S+0.8 MPa (100 psi) CO_2

Alloy Condition	5% NaCl+0.5% acetic acid at 177°C (350°F)	25% NaCl+0.5 acetic acid at 232°C (450°F)
Mill annealed	No cracking (14 days)	No cracking (30 days)
Cold rolled 23%	No cracking (14 days)	Cracked (7 days)

Corrosion Resistance of RA333 in a Simulated Deep Sour Gas Solution of 25% NaCl+0.5% Acetic Acid at 232°C (450°F) and containing 0.8 MPa (100 psi) H_2S and 0.8 MPa (100 psi) CO_2

	Average Corrosion Rate for Duplicate Specimens	
Alloy Condition	mpy	mdd
Mill annealed	0.24	(1.4)
Cold rolled 23%	0.23	(1.3)

Material Tested Heat 7951 12 gauge (2.5 mm) sheet

Chemical Analysis

Cr	Ni	Mo	Co	W	Mn	Si	C	P	S	Fe
25.09	44.84	3.15	3.11	3.09	1.80	1.44	0.042	0.017	0.005	Bal

Room Temperature Tensile Properties of RA333 Heat 7951

	0.2% Offset Yield Strength		Ultimate Tensile Strength,		% Elongation
Condition	ksi	(MPa)	ksi	(MPa)	in 50 mm (2 in.)
Mill annealed	48.3	(333.0)	104.0	(717.0)	52.9
Cold reduced 23%	121.9	(840.4)	134.5	(927.2)	1.8

Stress Corrosion Cracking

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RA333 Laboratory Tests and Brine Well Exposure

1. General Corrosion in ASTM D-1141 Substitue Seawater 0.18 mil/year (1.0 mdd) average of four tests. Little if any pitting, no crevice corrosion. 75°F (24°C) test temperature.

2. General Corrosion, 75°F, (24°C) in NACE TM-01-77 solution 5% NaCl + 0.5% CH_3COOH + H_2S 0.02 mil/year (0.11 mdd).

3. Stress Corrosion Cracking, NACE TM-01-77 75°F Stress 81% of 0.2% yield (109,000 psi 752 MPa). No cracking in 1000 hours. Stress 95% of 0.2% yield, 119,000 psi 820MPa. No cracking in 1000 hours.

4. Corrosion in heavy brine well saturated with CO_2, H_2S and CH_4, bromine present. Temperature 210°F (99°C) exposure approximately 90 days. 0.066 mil/year (0.38 mdd). Location Magnolia, Arkansas.

All the above tests were conducted on 0.670" dia. (17mm) as cold-drawn bar [cold drawn 20% from 0.75" dia (19 mm) hot rolled annealed heat 38253].

Tensile Properties, duplicate tests, are as follows:

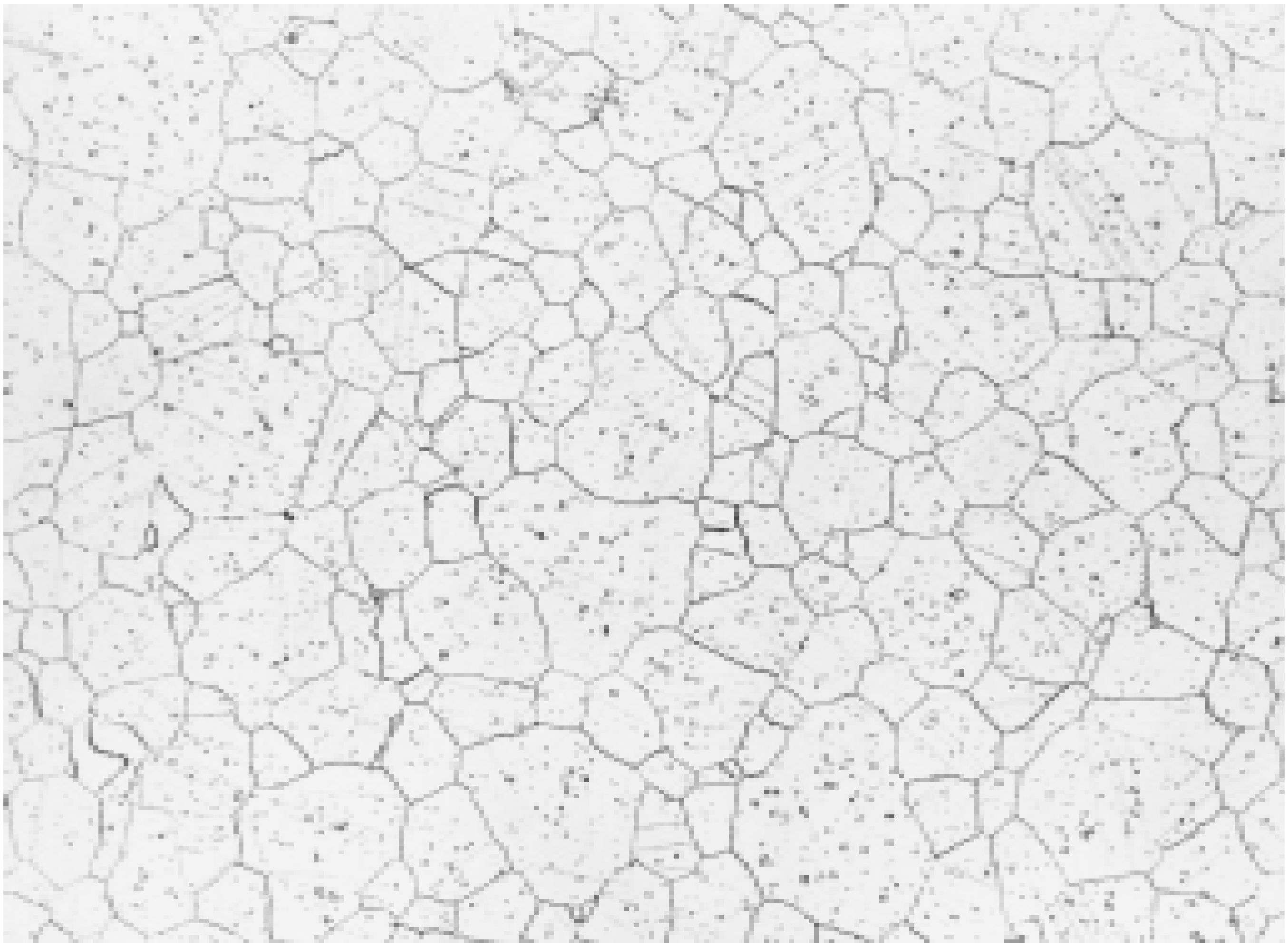
Test Temp°F (°C)	0.2% Offset Yield Strength psi	(MPa)	Ultimate Tensile Strength psi	(MPa5)	%El in 4D	% RA
75 (24)	132,400	(913)	146,900	(1013)	17.5	56.7
	136,500	(941)	147,200	(1015)	18.0	58.2
450 (232)	126,400	(871)	129,700	(894)	15.3	53.9
	124,500	(858)	129,600	(894)	15.2	55.0

One more sample of hot rolled annealed 16 gauge (1.6 mm) sheet, heat 70751 was exposed in a well with high pressure SO_2 saturated with brine vapor, approx. 150°F, corrosion rate 0.045 mil/year (0.26 mdd).

Heat Analysis

Heat No.	C	P	S	Si	Mn	Ni	Cr	Mo	Co	W	Fe
38253	0.045	.018	.005	1.06	1.69	44.85	24.54	3.03	3.06	3.00	balance
70751	0.04	.012	.007	1.23	1.71	45.95	25.55	2.99	3.01	3.05	balance

Metallography



Typical Microstructure of Mill Annealed RA333

165x; Etchant, Mixed Acids (25 parts HCl, 10 parts alcohol, 7 parts HNO_3); Average grain size ASTM-5

(Transverse sample taken from bar stock)

Other suggested etchants:

Marble's reagent -- 4g cupric sulfate, 20 ml HCl, 20 ml H_20

Electrolytic -- 10% oxalic acid in H_20

Electropolishing --82% methanol, 8%, H_2S0_4, 3% HNO_3, 2% HF, 5% lactic acid at -10 to -20°C. Jet polishing for transmission electron microscopy may be done with the same solution, cooled -40 to -50°C, 25 volts.

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The world's heat, corrosion, titanium, and aerospace alloy specialists.

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Trademarks

E-BRITE	ATI Properties, Inc.
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