RADATA SHEET

RA446 alloy

FEATURES

- Oxidation resistance to 2200°F
- Sulfidation resistance
- Availability
- Resists attack by molten copper alloys

APPLICATIONS

- Recuperators
- Combustion chambers
- Soot blowers
- Neutral salt pot electrodes
- Oil burner components
- Spouts for conveying molten copper alloys
- Kiln linings
- Thermocouple protection tubes
- Stack dampers
- Boiler baffles
- Gas-injection nozzles for various molten compounds
- Flame rods

Composition

Chromium	23.00 - 27.00
Carbon	0.15 max
Nitrogen	0.25 max
Manganese	1.50 max
Silicon	1.00 max
Phosphorus	0.040 max
Sulfur	0.030 max
Iron	balance

Specifications

UNS S44600	W. Nr. 1.4763 similar

ASTM A 176, A 276

General

RA446 is a high chromium ferritic heat resisting alloy with excellent resistance to oxidation and to various forms of hot corrosion.[1] The alloy is most commonly used for service between 1500 and 2200°F (815 and 1200°C), although its elevated temperature strength is quite low.

RA446, in common with other high chromium ferritics, embrittles severely when held in, or cooled slowly through the 700-1000°F (370-540°C) temperature range. This phenomenon is referred to as 885°F (475°C) embrittlement. RA446 should not be used in this temperature range unless nearly complete loss of room temperature ductility may be tolerated.

RA446 is also subject to room temperature embrittlement from sigma phase formation after long time service in the 1000-1300°F (540-700°C) temperature range.

Both 885°F and sigma phase embrittlements are reversible, and ductility may be restored by annealing.

Molten Metal Corrosion

Unlike austenitic stainless or nickel alloys, RA446 resists intergranular penetration by molten copper or silver alloys. RA446, like other metals, is not particularly resistant to molten aluminum.

Welding

RA446 is welded using most conventional welding processes. Austenitic weld fillers, such as RA 310-15 or 29Cr-9Ni welding electrodes, are generally suggested for a ductile weld deposit. When highly sulfidizing conditions exist such that nickel cannot be tolerated in the weld, or where the higher thermal expansion of austenitic weld filler is unacceptable, 446 type electrodes may be required. The use of 446 electrodes, however, results in a brittle, notch-sensitive weld bead.

An increase in notch sensitivity takes place in the heat affected zone of weldments as a result of grain growth. Stringer bead deposit technique using small diameter electrodes lessons grain growth tendencies in the heat affected zone.

Preheating and postheating 300-600°F (150-315°C) may be helpful in controlling base metal cracking. Light sections have been successfully joined with austenitic filler metals without pre- or postheating.

Forming

RA446 is notch sensitive and has low impact strength at room temperature. Careful edge preparation and preheating, especially in heavier sections, are desirable to avoid cracking during forming operations. Reduced forming speeds are preferred.

Edge preparation is especially important. Cold worked material on sheared or punched edges should be removed prior to heavy forming operations.

Toughness may be significantly improved by preheating 250-400°F (120-200°C) for any bending, drawing, or spinning operations. Increased incidence of cracking at scratches or notches may be expected when forming heavy sections at metal temperature below 120°F (50°C).

In marked contrast to the austenitic alloys, RA446 in the 1400-1500°F (760-815°C) temperature range has greatly increased ductility and is readily hot formed. Care should be taken to remain below 1600°F (870°C) in hot forming to ensure that grain growth does not occur.

Forging RA446 is performed by heating the workpiece uniformly throughout its section to a starting temperature of 1900-2100°F (1035-1150°C). It is suggested that large sections be preheated 1400-1500°F (760-815°C) prior to heating to the starting temperature. Finishing at relatively low temperatures, 1300-1450°F (700-790°C), is necessary for grain refinement.

Residual strains from forging or hot forming operations may be removed by a 1550°F (840°C) anneal.

Heat Treatment

RA446 is a ferritic alloy and cannot be strengthened by thermal treatment. Annealing is performed to remove the effects of cold work. The suggested procedure is to heat 1500-1600°F (815-870°C) long enough to ensure uniform metal temperature, followed by water quench or rapid air cool. Fast cooling through the 1100-700°F (590-370°C) temperature range is important to avoid 885°F embrittlement. A temperature of 1650°F (900°C) should not be exceeded during annealing or rapid grain coarsening may occur. Weldments may be stress relieved at somewhat lower temperature, 1350-1400°F (735-760°C), followed by rapid air cool or water quench, depending upon thickness and complexity of the welded fabrication.

Both sigma phase and the effects of 885°F embrittlement may be removed by a one hour anneal at 1500°F (840°C), rapid cool. Ductility may be largely restored after 885°F embrittlement by heating 1200°F (650°C) for one hour at temperature, rapid cool.

Machining

Machine tools and set-up should be rigid. Slow speeds and deep cuts are suggested to minimize work hardening. Sulfur-chlorinated cutting oils are suggested, thinned when necessary with parafin oil. Machinability rating is about 40-60% relative to B 1112 screw machine stock.

All traces of cutting fluid should be removed prior to welding, annealing, or use in high temperature service. Otherwise, residual sulfur or chlorine may attack the metal at elevated temperature.

Cleaning and Pickling

Machining lubricants may be removed from RA446 by alkaline cleaning agents or suitable solvents. Light scale may be removed by nitric-hydrofluoric pickling solutions. Heavy scale may require pretreatment by sand blasting or molten salt baths, followed by nitric or nitric-hydrofluoric acid pickling.

RA446 PROPERTIES

Physical Properties

Density
0.270 lb/cu. in.
7470 kg/m³

Melting Range
2640-2710°F
1450-1488°C

Permeability, Annealed[2]
μ=62.8 at H = 200 oersted

Specific Heat
0.12 Btu/lb•°F
500 J/kg•K

Thermal Conductivity[3]

Temperature, °F	Btu•ft/ft²•hr•°F	W/m•K
32	13.1	22.6
212	13.8	23.8
392	14.7	25.5
572	15.7	27.2
752	16.4	28.5
932	17.4	30.1
1112	18.4	31.8
1292	19.3	33.5
1472	20.3	35.1
1652	21.0	36.4

Electrical Resistivity[3]

Temperature, °F	ohm•circ mil/ft	microhm•m
32	345	0.57
212	420	0.69
392	480	0.80
572	540	0.89
752	590	0.98
932	640	1.06
1112	685	1.14
1292	715	1.19
1472	735	1.22
1652	745	1.23

Mean Coefficient of Thermal Expansion[4, 5]

Temperature Range °F	in/in.°Fx10^{-6}	m/m•K x 10^{-6}
70- 200	5.7	10.3
70- 500	5.8	10.4
70- 800	6.0	10.8
70-1000	6.1	11.0
70-1200	6.3	11.3
70-1400	6.4	11.5
70-1600	6.7	12.1
70-1800	7.3	13.1

Elastic Properties[6] (dynamic)

Temperature °F	Modulus of Elasticity psi x 10^6	Modulus of Rigidity (shear) psi x 10^6	Poisson's Ratio
80	30.4	11.9	0.28
200	29.8	11.6	0.282
400	28.7	11.2	0.285
600	27.7	10.7	0.29
800	26.0	10.0	0.30
1000	24.0	–	–
1200	20.0	–	–

Mechanical Properties

Typical Room Temperature

Mechanical Properties, Annealed

Ultimate tensile strength, psi	77,000
0.2% Offset yield strength, psi	50,000
Elongation, %	30
Reduction of area, %	58
Hardness, Rockwell B	80-94

Short-Time Elevated Temperature Tensile Properties, Annealed[7]

Test Temperature °F	Ultimate Tensile Strength psi	0.2% Yield Strength psi	Elongation %	Reduction of Area %
70	68,000	49,700	34	63
200	70,700	45,000	23	64
300	69,700	42,700	31	61
400	69,300	40,700	29	59
500	76,300	39,000	24	54
600	80,000	39,700	24	52
700	79,300	40,700	23	51
800	77,000	45,000	22	50
900	66,700	53,000	26	55
1000	52,700	42,300	27	63
1100	27,700	23,000	65	83
1200	15,000	12,000	90	92
1300	10,500	9,000	113	94
1400	5,000	4,000	128	97

Note: At sufficiently high temperature, metals deform with time under load, even if stressed below the tensile yield point. This deformation is known as creep. In the elevated temperature range where RA446 is used to resist oxidation and hot corrosion, its mechanical strength is best defined by creep or rupture data, and not by short-time tensile properties.

Stress to Rupture, psi[7, 8] (MPa)

Temperature °F	100 hour	1000 hour	10,000 hour
1100	8000 (55.2)	5200 (35.9)	3500 (24.1)
1200	6000 (41.4)	4000 (27.6)	2700 (18.6)
1400	2400 (16.5)	1600 (11.0)	1100 (7.58)
1600	1200 (8.27)	740 (5.10)	450 (3.10)
1800	670 (4.62)	400 (2.76)	230 (1.59)

Creep Strength[7, 8]

Temperature °F	Stress, psi, (MPa), for secondary creep rate of: 0.0001 %/hr	0.001 %/hr
900	16,000 (110)	20,000 (138)
1000	6,000 (41.4)	8,000 (55.2)
1100	3,000 (20.7)	4,500 (31.0)
1200	1,500 (10.3)	2,500 (17.2)
1300	680 (4.69)	1,400 (9.65)
1400	260 (1.79)	560 (3.86)
1500	130 (.896)	– –

Properties listed in this bulletin are typical or average values based on the published literature and on laboratory tests conducted for Rolled Alloys. These data should not be considered as guaranteed maximums or minimums. Materials must be tested under actual service conditions to determine suitability for a particular application.

References

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MIDWEST REGION:
125 W. Sterns Road • Temperance, Michigan 48182-9546 USA • 734-847-0561 • 800-521-0332 • FAX: 734-847-6917
CENTRAL REGION:
9944 Princeton-Glendale Road • Cincinnati, Ohio 45246 USA • 800-521-0332
EASTERN REGION:
30 Baker Hollow Road • Windsor, Connecticut 06095 USA • 800-227-7862 • 860-687-2140 • FAX: 860-687-2150
SOUTHERN REGION:
9818 E. Hardy Rd. • Houston, Texas 77093 USA • 800-728-1440 • 713-691-1040 • FAX: 713-691-0834
CANADA:
Rolled Alloys-Canada, Inc. • 100 Westmore Drive, Unit 12C • Toronto, Ontario, Canada M9V 5C3 • 416-745-2660
800-521-0332 • FAX: 416-745-2770
ENGLAND:
Rolled Alloys, Ltd. • Grangefield Industrial Estate • Grangefield Road • Pudsey, Leeds (UK) LS28 6JT
TEL: +44-(0)113-236-2992 • FAX: +44-(0)113-236-2575
NETHERLANDS:
Rolled Alloys BV • Christiaan Huygensstraat 25 • 3331 EA Zwijndrecht • TEL: +31-(0)78-6122622
FAX: + 31-(0)78-6193078
INTERNATIONAL:
Rolled Alloys International, Ltd. • 14, The Oaks, Clews Road • Redditch, Worcestershire (UK) B98 7ST
TEL: +44-(0)1527-401101 • FAX: + 44-(0)1527-401013
http://www.rolledalloys.com • e-mail: rolled@glasscity.net