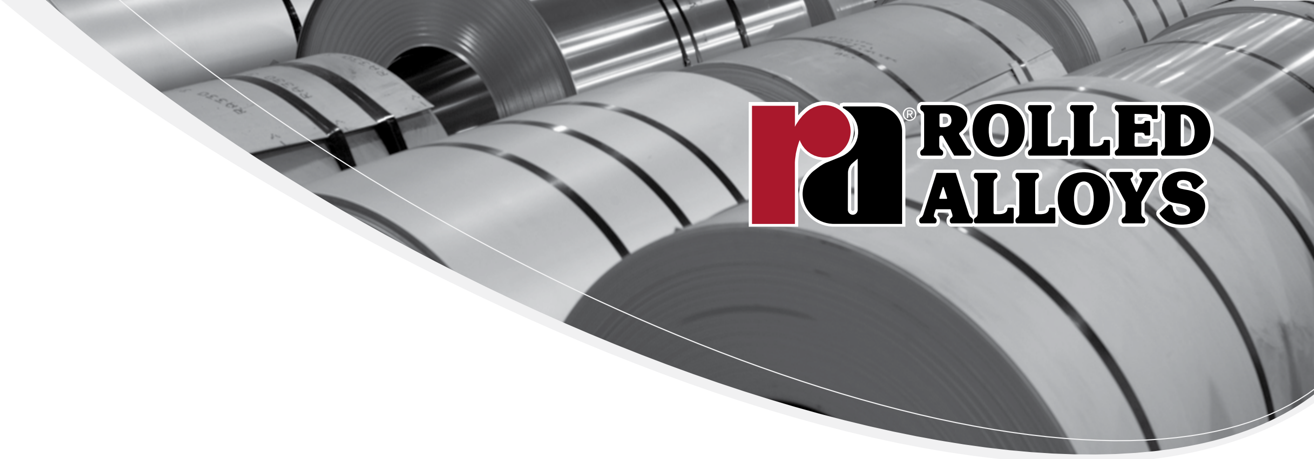
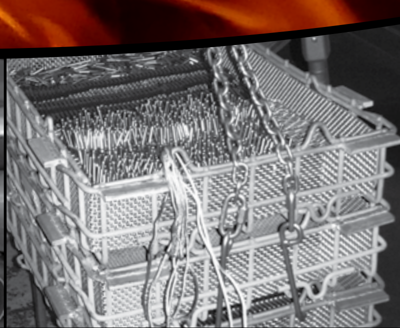


ROLLED ALLOYS

RA 602 CA® Data Sheet

RA 602 CA provides some of the best combined high temperature properties of any nickel alloy available. With good oxidation resistance up to 2250°F, RA 602 CA is used in the most demanding environments in the thermal processing industry.



The Global Leader in Specialty Metals

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RA 602 CA® is one of the most oxidation resistant high strength nickel heat resistant alloys available. High chromium, aluminum, and an yttrium addition permit it to develop a tight chromium oxide scale with an alumina subscale. RA 602 CA may be considered where it is important to minimize product contamination at extreme temperatures. A nominal 0.2% carbon content contributes to high creep rupture strength. Microalloying with zirconium minimizes grain growth upon exposure to temperatures above 1800°F.

Specifications

UNS: N06025 **W. Nr./EN:** 2.4633 **ASTM:** B 168, B 166 **ASME:** SB-168, SB-166, Code Case 2359

Chemical Composition, %

	Cr	Ni	Cu	P	S	Fe	C	Al	Ti	Y	Zr	Si	Mn
MIN	24.0	–	–	–	–	8.0	0.15	1.8	0.1	0.05	0.01	–	–
MAX	26.0	Balance	0.1	0.02	0.01	11.0	0.25	2.4	0.2	0.12	0.1	0.5	0.15

Features

- Resistance to cyclic oxidation through 2250°F
- Excellent high temperature creep-rupture strength
- Great resistant to carburization
- Superior resistance to oxidizing environments
- Superior resistance to chloridizing environments
- ASME Code Case to 1800°F

Applications

- Calciners for mineral processing
- Heat treating muffles and retorts
- Chemical vapor deposition retorts
- Vacuum furnace fixtures
- Nitric acid catalyst support grids
- Molten glass processing equipment
- Radiant heating tubes
- Carbon fiber production

Physical Properties

Density: 0.285 lb/in³ **Melting Range:** 2350 - 2550°F

Temperature, °F	68	1000	1200	1400	1600	1800	2000
Coefficient of Thermal Expansion* in/in°F x 10^{-6}	–	8.2	8.5	9.0	9.5	9.7	9.8
Thermal Conductivity Btu • ft/ft² • hr • °F	6.5	11.6	12.3	13.8	14.8	15.8	16.9
Modulus of Elasticity, Dynamic psi x 10^6	30.0	25.4	24.1	22.5	20.6	18.4	16.1

** 68°F to indicated temperature.*

Mechanical Properties

Representative Tensile Properties

Temperature, °F	68	1000	1500	1600	1800	2000	2200
Ultimate Tensile Strength, ksi	105	93.4	41.2	32.8	17.1	13	5.8
0.2% Yield Strength, ksi	50.5	38.3	34.8	28.7	15.2	11.6	5.0
Elongation, %	38	43	78	82	78	85	96

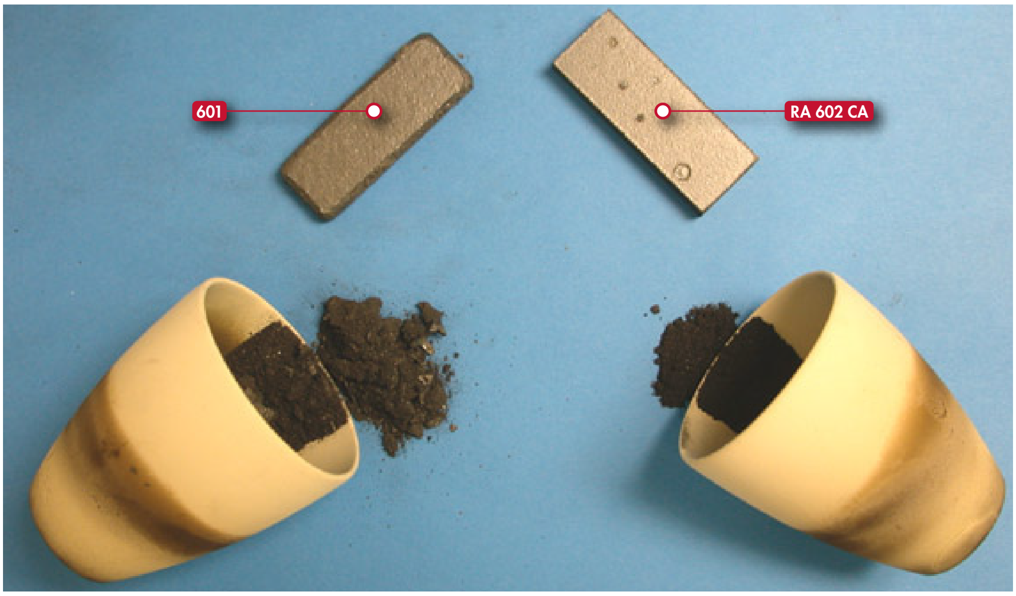
Typical Creep- Rupture Properties

Temperature, °F	1400	1600	1800	1900	2000	2100
Minimum Creep 0.0001%/Hour, ksi	9.4	2.4	0.96	0.59	–	–
10,000 Hour Rupture Strength, ksi	11.3	3.2	1.5	0.99	0.67	0.44

Oxidation Resistance

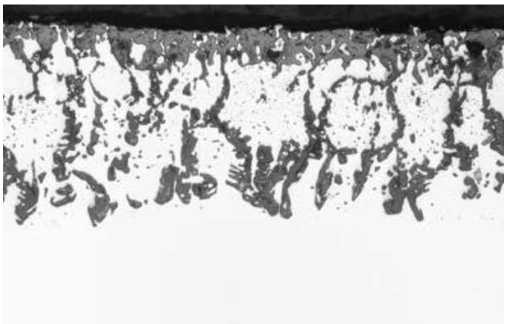
RA 602 CA is one of the most oxidation resistant nickel alloys available. Outstanding oxidation resistance is achieved through a high chromium content (25%) supplemented with aluminum (2.2%) and a microalloying addition of yttrium (0.1%). High chromium contents are known to be beneficial for resisting oxidation. The aluminum addition allows for the formation of a continuous homogenous self repairing Al_2O_3 subscale. The addition of yttrium improves the adhesion and spalling resistance of the chromium and aluminum oxide scales. The extremely low scaling rate of RA 602 CA makes it an excellent candidate for applications such as calciners, where minimal contamination from scaling is permissible.

The images below and on the following page compare the appearance of RA 602 CA versus 601 after more than 3000 hours in oxidation testing at 2250°F and 2100°F. Alloy 601, as seen, has extensive internal oxidation attack[6]. In contrast, only a thin surface oxide scale formed on RA 602 CA[2] during testing at 2100°F. This is especially important in applications that use thin sheet such as radiant tubes. No internal oxidation means the entire wall thickness is sound metal and the alloy retains a greater amount of its original properties.



RA 602 CA vs alloy 601 after 3026 hours at 2250°F.

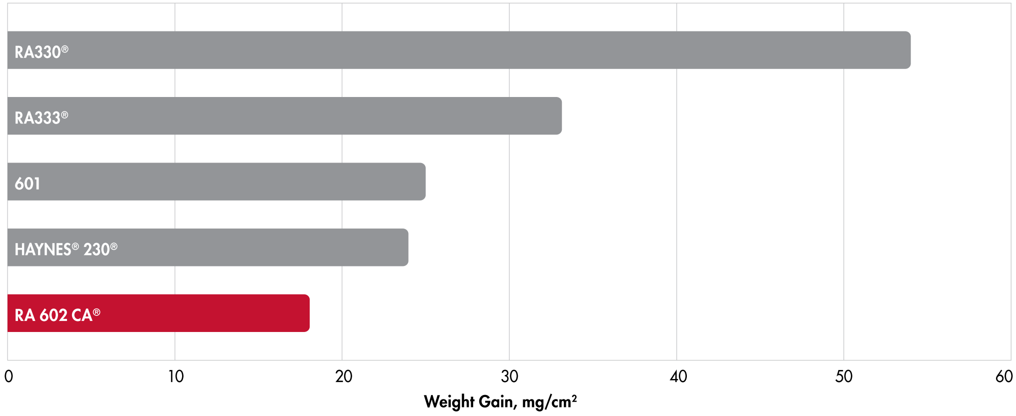
RA 602 CA after 3150 hours exposure to 2100°F Magnification: 200x



601 after 3150 hours exposure to 2100°F Magnification: 200x

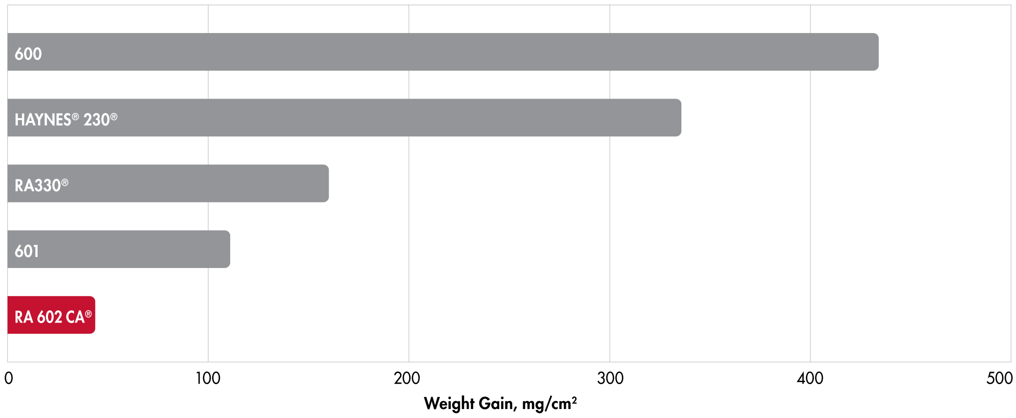
Cyclic Oxidation

2100°F, 3,000 Hours



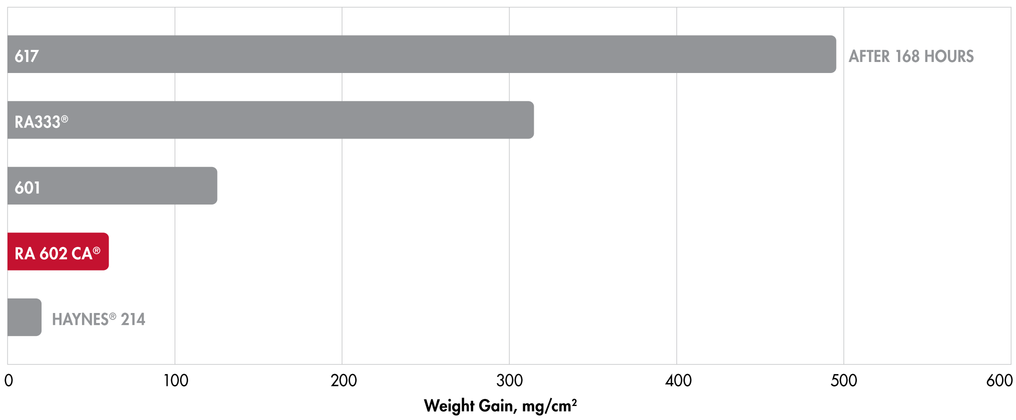
Cyclic Oxidation

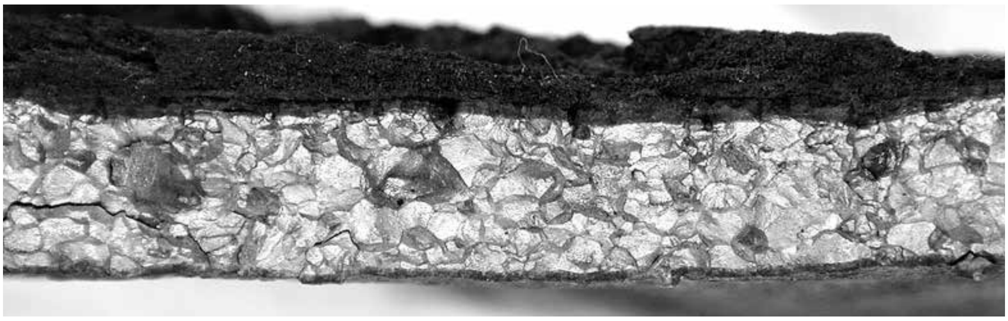
2200°F, 3,040 Hours



Cyclic Oxidation

2250°F, 3,000 Hours





Grain Growth

The brittle fracture of components exposed to extreme temperatures is a common occurrence. At temperatures near or exceeding the annealing temperature of a heat resistant alloy, grain growth is likely to occur. Extensive grain growth can result in a loss of ductility. As a result, the component can be prone to brittle fracture. An alloy 601 corrugated muffle that suffered brittle fracture due to combination of extensive grain growth and carburization is shown above.

The results of testing at 2050°F are detailed in the table below. The information provides a comparison of various heat resisting alloys that are commonly used above 1900°F. The data was compiled from intermittent exposure of sample coupons to 2050°F for a total of 990 hours. Each sample was in the mill annealed condition.

ASTM Grain Size

Effects of High Temperature Exposure on ASTM Grain Size[7] - 2050°F

Time, hours	0	2	24	72	184	344	510	670	830	990
RA 602 CA	7	7	7	7	6.5	6.5	6.5	6.5	6.5	6.5
601	5	5	1.5	1	1	0	0	00	00	00
601 GC	5.5	5.5	5	5	3.5	3.5	3	3	3	2.5
RA330	7	3.5	3.5	3	3	2.5	2	2	2	1.5
RA333	4	4	4	3	2.5	2	2	2	2	1
600	8	4	4	0	0	0	00	00	00	00

Carburization

Extended exposure to methane (CH_4), carbon monoxide (CO), and other carbon rich gases can lead to carburization. As heat resistant alloys absorb carbon, their ductility will gradually decrease. Alloys that are high in nickel, such as RA 602 CA possess excellent resistance to carburization attack[8]. RA 602 CA forms a tenacious oxide scale, which provides increased protection from carburization. This protective scale impedes the carbon from being absorbed into the base metal.

Cyclic Carburization

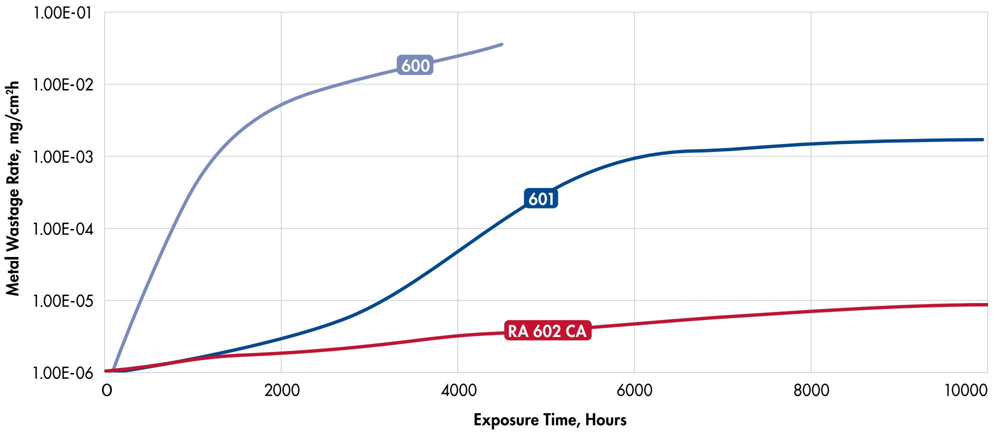
Cyclic Carburization in CH_4/H_2 Environment (A_C=0.8), Weight Change (mg/m^2h)

Temperature, °F	1562	1832	2102
310	130	305	–
800AT	143	339	813
600	50	190	626
601	64	170	508
RA 602 CA	13	70	175

Metal Dusting

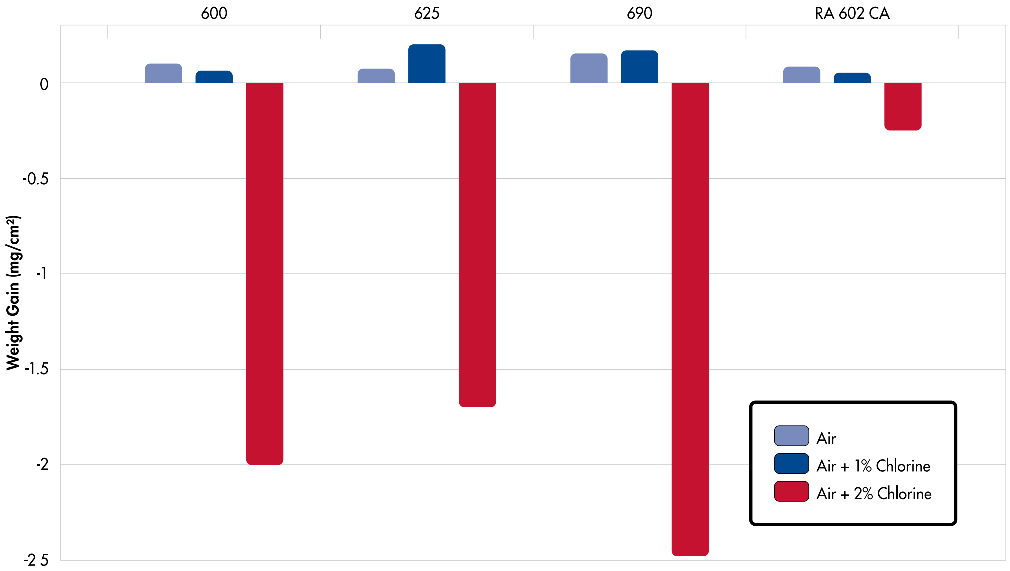
Metal dusting is a form of carburization that can lead to the rapid corrosion of heat resistant alloys. The combination of high aluminum and chromium additions to RA 602 CA results in a resistance to metal dusting superior to alloys such as RA330, 600, 601, and 800H/AT.

Coupon testing of alloys in simulated metal dusting atmosphere consisting of H_2+CO+H_2O at 1202°F



Hot Corrosion

1472°F, Exposed 100 Hours



Creep-Rupture[3]

RA 602 CA possesses excellent creep rupture properties. The relatively high carbon level in the alloy ensures the precipitation of bulky homogeneously distributed carbides. Alloying with titanium and zirconium ensures that these carbides and also carbonitrides are finely distributed. Even solution annealing at 2192°F does not completely dissolve these carbides. As a result, the alloy achieves its high creep strength through a combination of solid solution hardening and carbide strengthening.

RA 602 CA has a strength advantage over 601 at all temperatures. At temperatures above 1800°F, RA 602 CA has equivalent or greater creep rupture properties than HAYNES 230 alloy.

Average Stress to Rupture, ksi

Grain size 70 µm or coarser (ASTM 4.5 or coarser)

Temperature, °F	1200	1400	1600	1700	1800	1900	2000	2100
1,000 hours	37.7	17.4	4.6	3.6	2.3	1.7	1.25	0.67
10,000 hours	31.2	11.3	3.2	2.18	1.49	0.99	0.67	0.44
100,000 hours	20.3	5.8	1.75	1.1	0.74	0.49	0.31*	0.2*

* *Extrapolated*

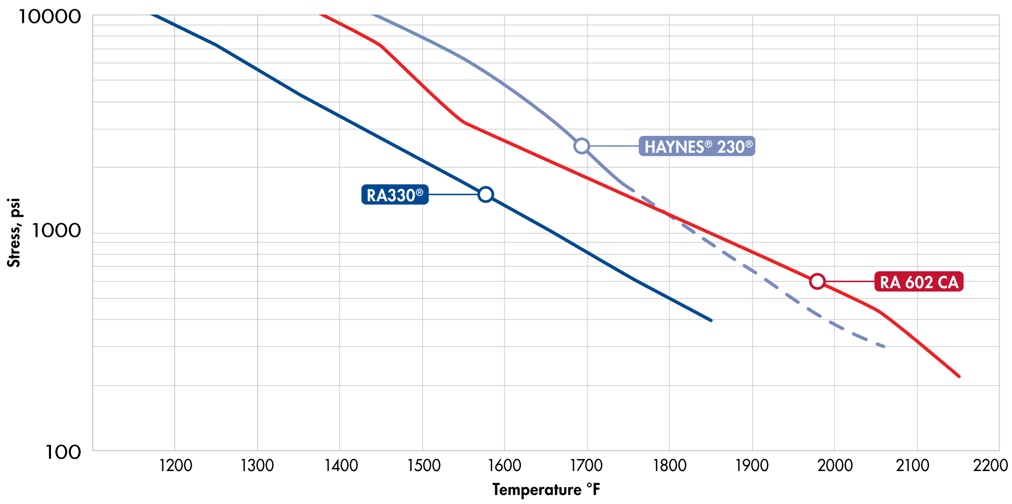
Stress for 1% Total Creep, ksi

Grain size 70 µm or coarser (ASTM 4.5 or coarser)

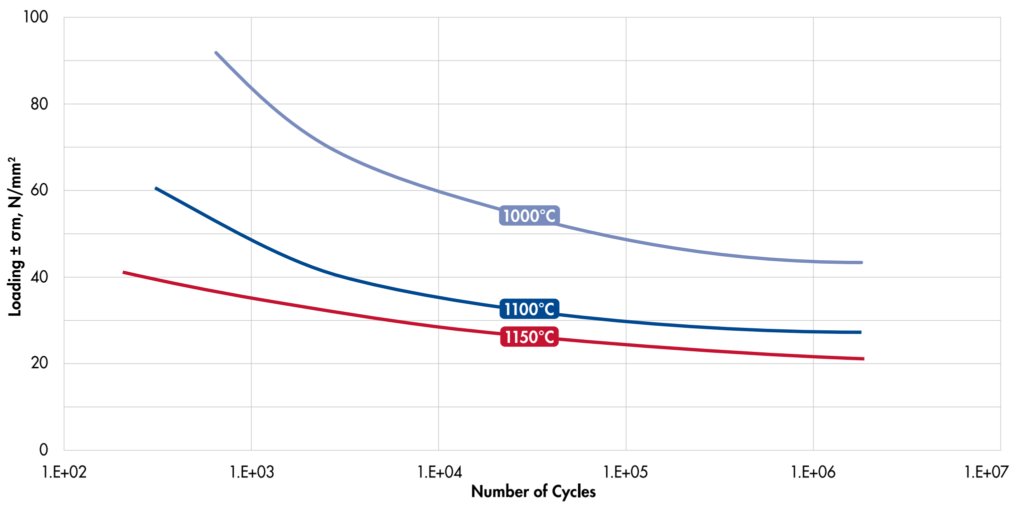
Temperature, °F	1200	1400	1600	1700	1800	1900	2000	2100
1,000 hours	31.9	13.9	3.5	2.23	1.3	0.81	0.54	0.26
10,000 hours	26.8	9.4	2.38	1.52	0.96	0.59	0.33	0.14
100,000 hours	20.9	5.4	1.3	0.91	0.58	0.32	0.16*	0.06*

* *Extrapolated*

Rupture Strength



Fatigue



Impact Properties

Effects of Long Term Exposure at Elevated Temperatures on Ductility[3]

Temperature, °F	Condition	Time at Aging Temperature	Impact Strength, ft-lb
–	Annealed	0	58 - 62
932	Annealed	8000	22.1
1184	Annealed	8000	22.1
1364	Annealed	8000	20
1544	Annealed	8000	42.8
932	10% Cold Worked	8000	16.2
1184	10% Cold Worked	8000	20
1364	10% Cold Worked	8000	18.4
1544	10% Cold Worked	8000	50.2
932	10% Cold Worked + Aged + Annealed	8000	58
1184	10% Cold Worked + Aged + Annealed	8000	62.7
1364	10% Cold Worked + Aged + Annealed	8000	56.1
1544	10% Cold Worked + Aged + Annealed	8000	59

Hot Forming

RA 602 CA may be hot-worked in the temperature range 1650 - 2190°F, followed by water quenching or rapid air cool. As with other austenitic alloys, do not attempt to form in the 1100 - 1500°F temperature range.

Heating must be performed in a furnace with accurate temperature control, and a neutral to slightly oxidizing atmosphere. The atmosphere should not fluctuate between oxidizing and reducing. Natural gas used to fire the furnace should contain no more than 0.1 weight % sulfur, and fuel oil no more than 0.5% sulfur.

The flame must not impinge directly on the workpiece. Do not heat RA 602 CA, or any other nickel alloy, with a torch to bend it. The lack of temperature control will often result in cracking.

Cold Forming

RA 602 CA has a high carbon content, and work hardens rapidly. RA 602 CA may be bent 120° around a radius equal to four times the material thickness (4T bend) for material up to 0.4" thick. This grade cannot be bent to as tight a radius as the lower carbon alloys, e.g. alloy 600 or RA330.

As with other nickel alloys, the shear drag (burr) should be removed, or placed on the inside of the bend. During bending this heavily cold-worked burr may initiate cracking. Sawed plate may be preferred for severe forming operations.

Heat Treatment

RA 602 CA is solution annealed at 2160-2230°F followed by water quenching. For sheet 16 gage and lighter, rapid air cooling is acceptable.

Dissimilar Welding

RA 602 CA may be welded to carbon steel, 304 stainless steel, or Alloy 600 using ERNiCr-3 (Alloy 82) bare wire or ENiCrFe-3 (Alloy 182) covered electrodes.

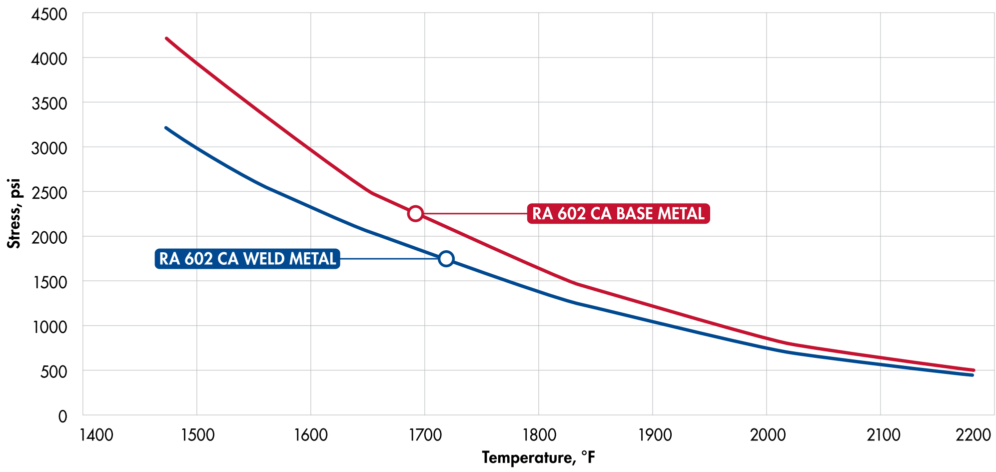
Joints between RA 602 CA and Alloy 601 may be made using the matching RA 602 CA weld filler, NICROFER 6025 HT. Weldments to other heat resistant or nickel alloys should be qualified before production. Choice of weld filler should be based on high temperature service properties, in addition to weldability considerations.

GTAW
Gas Tungsten Arc Welding

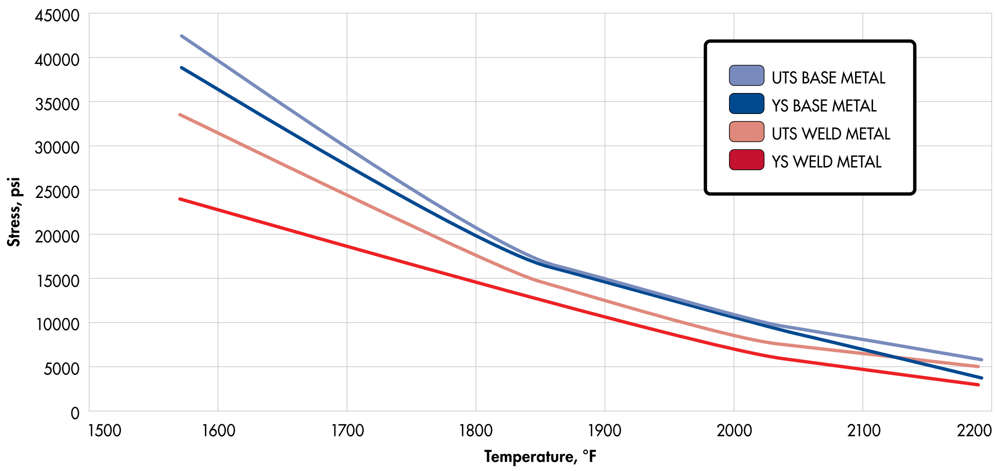
RA 602 CA may be joined by Gas Tungsten Arc Welding and by Plasma Arc Welding. In both cases the back side of the weld root must be shielded with 100% welding grade argon (not nitrogen). Good root shielding is required because of the high aluminum content of this alloy. The torch gas must be argon with 2-3% nitrogen added, for both processes. The 2-3% N_2 addition to the argon is necessary for improved weldability and reduced hot cracking susceptibility in RA 602 CA.

Interpass temperature should not exceed 250°F with lower temperatures preferred. Heat the metal before welding only if necessary to dry the workpiece, and then just hot to the touch. Neither preheat nor postheat is required. The matching weld filler wire is NICROFER 6025 HT, W.Nr. 2.4649, AWS ERNiCrFe-12.

10,000 Hour Stress to Rupture values of RA 602 CA GTAW weld as compared to RA 602 CA base metal.[12]



Comparison of mechanical properties of RA 602 CA Base Metal vs. GTAW welds made with matching filler



Manual GTAW Parameters, Shielding Gas: 98% Argon, 2% Nitrogen

Plate Thickness, in	Filler Metal Diameter, in	Root Pass, volts	Filler Pass, volts	Travel Speed, in/min	Arc Energy, KJ/in	Shielding Gas Flow, cfh
0.12	0.063	11	–	4 - 6	20	17 - 21
0.25	0.063 - 0.094	11	15	4 - 6	20	17 - 21
0.50	0.094	11	15	4 - 6	20	17 - 21

Automatic GTAW Parameters, Shielding Gas: 98% Argon, 2% Nitrogen

Plate Thickness, in	Filler Metal Diameter, in	Root Pass, volts	Filler Pass, volts	Travel Speed, in/min	Arc Energy, KJ/in	Shielding Gas Flow, cfh
0.12	0.035 - 0.045	MANUAL	10 - 15	8 - 12	20	30 - 40
0.3125	0.035 - 0.045	MANUAL	10 - 15	8 - 12	20	30 - 40

GMAW
Gas Metal Arc Welding

GMAW welding of RA 602 CA should be performed using the matching composition weld wire designated as NICROFER 6025 HT. RA 602 CA should be joined using the pulse arc process. It is recommended to utilize the welding gas CRONIGON® Ni 30 (90% Ar, 5% He, 5% N_2, plus 0.05% CO_2), available from Linde Gas to reduce the likelihood of centerline cracking.

For applications under 1832°F, RA 602 CA may be welded with alloy 617 wire, ERNiCrCoMo-1, using argon or argon-helium shielding gas. A GTAW cover pass with NICROFER 6025 HT filler wire is necessary to match the oxidation resistance of the RA 602 CA base metal. NICROFER 6025 HT weld filler should be used at higher temperatures where alloy 617 has less strength than RA 602 CA base metal.

Pulse Arc Transfer

Wire Diameter, in	Wire Feed, in/min	Amperes	Volts	Gas Flow, ft³/hr	Travel Speed, in/min	Pulse, pulse/sec
0.045	236	170	26	38	15	500

SMAW
Shielded Metal Arc Welding

Matching chemistry DC basic covered electrodes, 6225 Al (AWS ENiCrFe-12), are available for welding RA 602 CA. Use a stringer bead technique, electrode inclined approximately 20° in the direction of travel. Keep the interpass temperature low, below 300°F. Electrodes must be dry. If necessary, rebake to dry for 2 hours at 480°F.

6225 Al Electrode Weld Deposit[8] - Nominal Chemical Composition, %

Cr	Ni	C	Al	Ti	Y	Zr	Mn	Si	Fe
25	62	0.2	1.8	0.1	0.02	0.03	0.1	0.6	10

SMAW Weld Metal Mechanical Properties, Room Temperature (minimum)

Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Elongation, %	Impact Strength, ft-lb
101.5	72.5	15	22

SMAW Weld Metal Starting Parameters

Electrode diameter, inch	3/32	1/8	3/16
DCRP Current, Amps	40 - 55	70 - 90	90 - 110

PAW
Plasma Arc Welding

As with automatic GTAW, shielding gas must be Argon with 2-3% Nitrogen.

Plate Thickness, in	Filler Metal Diameter, in	Root Pass, volts	Filler Pass, volts	Travel Speed, in/min	Arc Energy, KJ/in	Shielding Gas Flow, cfh
3/16	0.045	25	–	10 - 12	28	65
1/2	0.045	25	10 - 12	28	65	–

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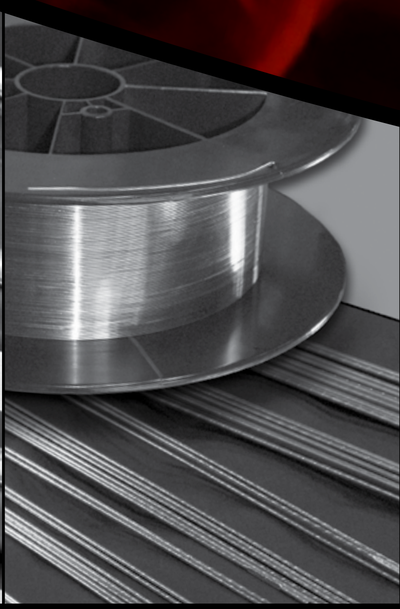

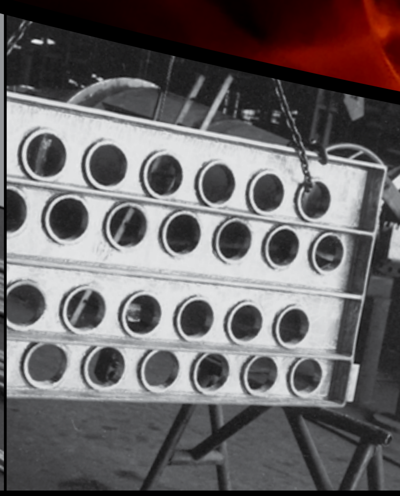

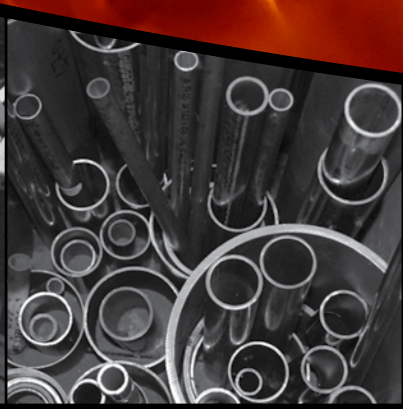

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