RA X alloy

FABRICATION

Technology Department

October, 1996

ROLLED ALLOYS

Heat and Corrosion Resistant Alloy Specialists

Revised
October 15, 1996 **Bulletin 211**

RA X alloy is welded with the matching chemistry AMS 5798 bare welding wire and AMS 5799 covered electrodes.

This manual is based on input from Allegheny Ludlum Corp., Haynes International, Inc. Bulletin H-3159, and on Rolled Alloys' fabrication experience. Techniques for controlling distortion are from Avesta Sheffield Welding, AB, and Sandvik AB.

Rolled Alloys carries a broad inventory of RA X alloy sheet, plate, bar and welding wire. For price and delivery information contact Rolled Alloys at 800-521-0332, 313-847-0561, FAX 313-847-6917.

For additional copies of this bulletin, contact Rolled Alloys Marketing Services at the above numbers, or FAX 313-847-3915.

James Kelly
Director of Technology

Issued April, 1996

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I. RA X ALLOY DESCRIPTION

A. Mechanical and Physical Properties

RA X is one of the most widely used nickel base superalloys for gas turbine engine components. This solid solution strengthened grade has good strength and excellent oxidation resistance beyond 2000°F (1100°C). RA X is highly resistant to carburizing atmospheres and has been used for heat treating furnace components. Due to its high molybdenum content, RA X may be subject to catastrophic oxidation above 2100°F (1150°C).

The high nickel and molybdenum contents of RA X provide practical immunity to chloride ion stress corrosion cracking and high resistance to chloride pitting and crevice corrosion. The pitting resistance equivalent of RA X is 52, where (PRE) N = %Cr + 3.3%Mo + 30%N.

The specified chemistry range of RA X alloy is:

Cr	Ni	Mo	Co	W	Al	Ti	B	C	Fe
20.50	remainder	8.00	0.50	0.20	0.50	0.15	0.010	0.05	17.00
23.00	--	10.00	2.50	1.00	max	max	max	0.15	20.00

Mn	Si	P	S	Cu
1.00	1.00	0.040	0.030	0.50
max	max	max	max	max

Representative Tensile Properties, sheet

Temp °F	°C	Ultimate Tensile Strength psi	MPa	0.2% Yield Strength psi	Mpa	Elongation in 2 inch (50 mm) %
70	21	110,600	763	54,900	379	44
1000	538	89,000	614	35,600	245	49

I. RA X ALLOY DESCRIPTION

A. Mechanical and Physical Properties

Physical Properties, Average

Density: 0.297 lb/in^3 8221 kg/m^3
Melting Range: 2300 - 2470°F 1260 - 1354°C

Dynamic Modulus of Elasticity

Temperature °F	°C	psi x 10^6	GPa
70	21	29.8	205.5
1000	538	25.8	178
1200	649	24.7	170

Poisson's Ratio 72°F/22°C 0.320

Electrical Resistivity

70°F 712 ohm · circular mil/ft
20°C 1.18 microhm · m

Thermal Conductivity

Temperature °F	°C	Btu · ft/ft^2 · hr°F	W/m · K
70	21	5.6*	9.7
1000	538	11.3	19.6
1400	--	13.9	24.1
1800	--	16.4	28.4

* extrapolated

Mean Coefficient of Thermal Expansion

°F	°C	inch/inch · °F x 10^{-6}	m/m · K x 10^{-6}
78-200	25-93	7.7	13.9
-1000	-538	8.4	15.1
-1400	-760	8.8	15.8
-1800	-982	9.2	16.6

Magnetic Permeability

70°F (21°C) less than 1.002 at 200 Oersteds (15,900 A/m)

I. RA X ALLOY DESCRIPTION

B. Specifications

RA X is designated as UNS N06002 in the Unified Numbering System for alloys. In ASME section IX RA X is P No. 43 for welding, and P No. 111 for brazing. ASME Section VIII, Division 1 covers the use of RA X in welded construction through 1650°F. For external pressure design, use Figure NFN-15 of Section II, Part D.

Specifications

Alloy Form	ASTM AMS	ASME	Other
Plate, Sheet and Strip	5536	B 435 SB-435	--
Sheet, Plate	---	--	GE B50A436C
Sheet	--	--	GE B50T83A GE B50TF25A PDS 15102QE
Sheet, Strip and Plate Low Temperature	--	--	PWA 1038
Sheet, Low Temperature	--	--	GE B50TF24A
Rod	--	B 472 SB-472	B14H74A
Bars, Forgings and Rings	5754	--	--
Welding Wire	5798	SFA-5.14 ERNiCrMo-2	AWS A 5.14 ERNiCrMo-2
Welding Nickel and Nickel-Cobalt Alloy Pipe	--	B 619 SB-619	--

For Metal Temperature, °F, Exceeding	Maximum Allowable Stress, ksi (multiply by 1000 to obtain psi) TABLE 1B ASME Section VIII, Division 1 (ksi times 6.894757 equals MPa)	
	Notes	
	G1, G2	G1, G2, G7, G8
-20 to 100	23.3	23.3
200	20.9	23.3
300	19.2	23.3
400	17.8	22.9
500	16.5	22.3
600	15.6	21.1
650	15.3	20.7
700	15.0	20.3
750	14.9	20.1
800	14.7	19.8
850	14.6	19.7
900	14.5	19.6
950	14.4	19.5
1000	14.3	19.3
1050	14.2	19.3
1100	14.2	17.5
1150	14.1	14.1
1200	11.3	11.3
1250	9.3	9.3
1300	7.7	7.7
1350	6.1	6.1
1400	4.8	4.8
1450	3.8	3.8
1500	3.0	3.0
1550	2.3	2.3
1600	1.7	1.7
1650	1.2	1.2

In all cases, for welded pipe and tubing a joint efficiency factor of 0.85 must be applied. See page 266, 1995 Section II Part D.

II. PLATE CUTTING

RA X plate may be dry abrasive sawed, sheared or plasma arc cut. Shears rated for 1/4" mild steel are used up to 3/16" thick plate.

As with other Ni-Cr-Fe alloys, RA X cannot be cut by oxyfuel procedures. Plasma arc cutting, however, is used at Rolled Alloys to cut shapes in heavy RA X plate. Under 2" nitrogen suffices for the plasma/shielding gas. At around 2 inch or heavier plate an argon-hydrogen mixture gives a cleaner cut.

CAUTION: When using gases containing hydrogen, take care that they do not accumulate somewhere and cause an explosion. For example, when cutting over a water table, drop the water level below the plate to prevent hydrogen gas pockets from developing under the plate.

III. MACHINING

RA X alloy and other austenitic grades are quite ductile in the annealed condition. However, these chromium-nickel alloys work harden more rapidly and require more power to cut than do the plain carbon steels. Chips tend to be stringy, cold worked material of relatively high ductility.

Machine tools should be rigid and used to no more than 75% of their rated capacity. Both work piece and tool should be held rigidly; tool overhang should be minimized.

Make sure tools are always sharp. Change to sharpened tools at regular intervals rather than out of necessity. Remember, cutting edges, particularly throw-away inserts, are expendable. Don't try to prove how long they can last. Don't trade dollars in machine times for pennies in tool cost.

Turning operations require chip curlers or breakers.

Feed rate should be high enough to ensure that the tool cutting edge is getting under the previous cut thus avoiding work-hardened zones. Slow speeds are generally required with heavy cuts. Lubricants, such as sulfur-chlorinated petroleum oil, are suggested. Such lubricants may be thinned with paraffin oil for finish cuts at higher speeds. The tool should not ride on the work piece as this will work harden the material and result in early tool dulling or breakage.

Use an air jet directed on the tool when dry cutting. This can significantly increase tool life.

For band sawing we suggest a Lenox® Matrix 2 blade, variable pitch 2/3 teeth per inch for large billet, 3/4 per inch for smaller bar. Coolant mix should be rich, about 5:1 water to solvent. Blade set up should be rigid, with no gap. Speeds about 75 - 80 ft/minute (.38 - .41 m/s).

All traces of cutting fluid must be removed prior to welding, annealing, or use in high temperature service.

Suggested Feeds & Speeds, from Haynes International Bulletin H-3159

Turning, Boring and Facing

The following table represents a typical range of values for normal turning operations. The depth of cut (particularly for roughing operations) is quite large with relatively low feed rates. These parameters are equipment and component dependent. The larger depths of cuts and higher speeds are recommended only when using heavy, overpowered equipment on large rigid components.

III. MACHINING

Conditions	Roughing	Finishing
Depth of Cut	0.150 inch (3.8 mm)	0.040 inch (1 mm)
Feed Rate	0.004 - 0.008 ipr (0.1 - 0.2 mm/turn)	0.005 - 0.007 ipr (0.13 - 0.18 mm/turn)
Speed-Carbide	30 - 50 sfpm (9 - 15 m/minute)	95 - 110 sfpm (29 - 36 m/minute)

Drilling

High-speed steel heavy-web bits with 135° crankshaft point are suggested. For drill bits larger than 3/8" (10 mm), thinning the web may reduce thrust and aid chip control. The following are suggested speed and feed rates for various diameter drills.

Diameter		Speed			Feed Rate	
inch	mm	RPM	SFM	m/min	inch/rev	mm/turn
1/8	3	200 (max)	8 max	2.4	0.001	0.025
1/4	6	200 (max)	15 max	4.6 max	0.002	0.05
1/2	13	115	15	4.6	0.003	0.08
1"	25	57	15	4.6	0.007	0.18

Reaming

Standard fluted reamers of high-speed steel are generally used. Speeds should be about 10-15 sfpm (3 - 4.5 m/min) for diameters above 1/2 inch (13 mm). For smaller diameter reamers (less than 1/2 inch (13 mm) diameter) cutting speeds should be reduced substantially. Feed rates will range from 0.003 to 0.008 inch/revolution (0.08 - 0.20 mm/turn) depending upon diameter. If carbide tipped reamers are used, the speed can be increased to 40 sfpm (12 m/min) for reamers above 1/2 inch (13 mm) diameter. If chatter occurs, reduce speed.

IV. COLD FORMING

RA X alloy is formed in the same manner as other austenitic alloys. This grade has a high yield strength, with room temperature properties similar to those of RA333® alloy.

RA X plate can normally be press brake bent over a radius equal to the plate thickness. Note that the inside radius is determined by the radius on the male die. Bending over a sharp cornered male die or punch will often cause the plate to crack regardless of female die spacing or the radius on the outside of the bend.

With sheared plate it is good practice to remove the shear burr (or drag) to avoid cracking.

RA X can suffer extensive carbide precipitation and some embrittlement during long service exposures at 1200-1600ºF. Material in this condition should be solution annealed before severe cold forming is attemped. Excessive annealing, which will cause excessive grain growth, should also be avoided since coarse grain material exhibits reduced cold formability.

Surface finish can have a significant influence upon the cold formability ofo RA X. Material which has been heavily grit blasted to removed oxide scales may exhibit surface cracking when bent. Surface polishing with medium and/or fine grit abrasive (prior to forming) may eliminate such cracking.

Heavy duty lubricants may be used in cold forming to prevent galling and reduce die wear. Lubricants must be removed prior to welding, annealing or use in high temperature service, to avoid possible hot corrosive attack.

Sulfur-chlorinated lubricants, in particular, must be thoroughly removed. Lubricants containing either sulfur or chlorine should not be used for spinning. The spinning operation tends to burnish the lubricant into the surface of the metal, rendering complete removal difficult.

Forming at room temperature is suggested whenever possible.

No forming or bending should be performed at temperature while in the low ductility range of 1200 - 1600°F (650-870°C). Forming in this temperature range may cause intergranular tearing in austenitic alloys.

V. HOT WORKING

When hot working heat resistant alloys such as RA X, bear in mind that this alloy has high hot strength, work hardens rapidly, has a relatively low incipient melting temperature and low thermal conductivity.

Soak the workpiece for at least 1/2 hour at 2150ºF (1175°C) max for each inch (25 mm) of thickness. A properly calibrated optical pyrometer is essential. Avoid direct flame impingement. Turn the workpiece frequently to present the cooler side to the furnace atmosphere.

Moderately heavy reductions, 25 to 40 percent, are desirable to maintain as much internal heat as possible, minimizing grain growth and the number of reheatings. Avoid reductions greater than 40 percent per session.

Condition out any cracks or tears developed during forging. This can be done at intermediate stages between forging sessions. Unlike with 300 series stainless, excessively coarse grind lines will not be smoothed out by oxidation while soaking in the furnace.

Finish forging 1750ºF (955°C).

VI. HEAT TREATING

RA X is a fully austenitic alloy which does not harden by thermal treatment. Increased room temperature strength may be obtained only by cold working.

The purposes of annealing RA X are to remove residual forming stresses or to redissolve precipitated carbides. For many non-aerospace high temperature applications, RA X fabrications are not annealed after forming or welding.

If the final application requires a full anneal, the suggested procedure is to heat in a low sulfur atmosphere 2125 - 2175°F (1165 - 1190°C) long enough to ensure a uniform actual metal temperature, followed by rapid air cooling or quenching.

In order to avoid grain coarsening and consequent orange peel in severe forming operations of sheet, it is suggested that in-process annealing be done significantly lower than 2150°F (1177°C).

Note that the common stress relief temperature for carbon steel, 1100 - 1200°F (590-650°C), will remove only about 25% of the fabrication stresses in RA X. If complete stress relief is desired for some reason, e.g. when precision machining large components, it is necessary to heat 1850 - 1950°F(1010 - 1065°C), soak at least one half hour at temperature, then still air cool or, in the extreme, furnace cool until black. Quenching after "stress relief anneal" is undesirable, as it will simply reintroduce new stresses.

One disadvantage to this lower temperature anneal is that heavily cold worked areas may recrystallize to a very fine grain size, with consequent reduction in creep rupture strength.

VII. DESCALING & PICKLING

During high temperature exposure RA X forms a tenacious oxide scale which is not significantly attacked by acid pickling baths.

Annealing or hot working scale on RA X may be removed mechanically, by fused caustic-nitrate baths or by fused caustic-sodium hydride baths, in all cases followed by a nitric-hydrofluoric acid pickle.

Mechanical scale removal includes steel shot blasting, glass bead blasting, wet abrasive blasting or abrasive wheels. Such treatment is followed by immersion in a nitric-hydrofluoric acid bath to remove embedded iron, any remaining scale and the chromium depleted layer under the scale. It is necessary to use an acid bath more aggressive than the 10% nitric 2 - 3% hydrofluoric commonly used on stainless steel. This means reducing the nitric acid level while increasing hydrofluoric. One suggestion is 4% HNO_3 plus 4% HF at 120 - 140°F (49 - 60°C) for 30 minutes. Heating this bath above 140°F (60°C) may cause excessive fuming.

A typical oxidizing fused salt bath is about 70% dry sodium hydroxide (NaOH) and 30% sodium nitrate ($NaNO_3$), operated 800 to 1000°F (425 to 540°C). The nitrate oxidizes insoluble Cr^{+3} in the scale (chromia) to Cr^{+6} (sodium chromate), which is soluble.

NOTE: This bath is dangerous, explosions may occur from introduction of water or excessive organic compounds. Use proper safety precautions.

After being removed from the caustic-nitrate bath and quenched in water, the RA X is immersed in 5 - 10% sulfuric acid (H_2SO_4) at about 160°F (70°C) for 5 - 15 minutes. This neutralizes salt bath drag-out and dissolves the converted scale. As hexavalent chromium is a carcinogen proper disposal methods are imperative.

The last step is to brighten the metal in 4% nitric + 4% hydrofluoric 120 - 140°F (49 - 60°C), and water rinse.

Further information on descaling may be found in the ASM Metals Handbook series, Volume 5, Surface Engineering. This is available from ASM International, Materials Park, Ohio 44073-0002, U.S.A. PHONE: 216-338-5151, FAX: 216-338-4634. For commercial assistance in setting up and operating a fused salt bath descaling operation we suggest contacting: Kolene® Corporation, 12890 Westwood Avenue, Detroit, Michigan, 48223, U.S.A. PHONE: 313-273-9220, FAX: 313-273-5207.

VIII. WELDING

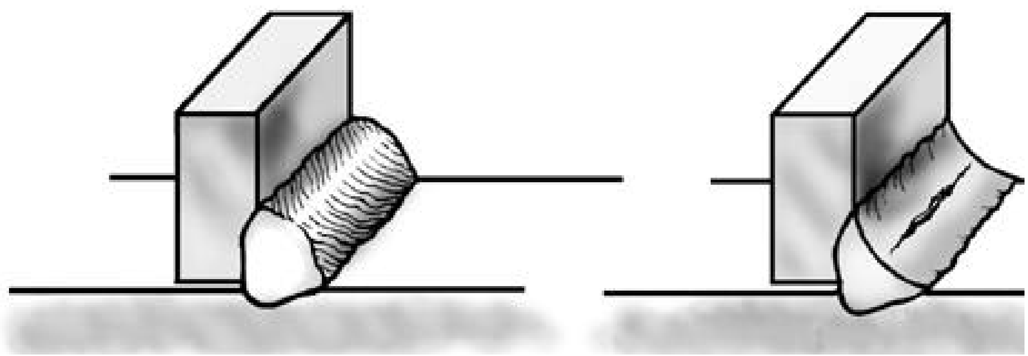
A. General

Both RA X and its weld fillers solidify directly from the melt as fully austenitic materials. That is, there is never any ferrite (FN) as would be expected with the lower nickel heat resistant grades such as RA309 or RA 253 MA®. For this reason, welding practice similar to that used with other high nickel alloys is required to avoid the possibility of hot cracking in restrained joints.

One important technique for ensuring a sound weld is to deposit a reinforced bead contour. Broad, flat or shallow beads are more susceptible to centerbead cracking.

Reinforced, convex beads provide greater resistance to hot tearing during welding.

Than does a shallow concave bead contour



Likewise, starting beads should be heavy to minimize chances of cracking. Craters at the end of a weld should be filled in.

VIII. WELDING

B. Heat Input, Interpass Temperature, Preheat and Cooling

1. Heat Input

Welding heat input should be as low as feasible for the joint involved, it is suggested to stay below 50 kilojoule per inch (2 kJ/mm), and preferably below 40 kJ/inch (1.6 kJ/mm).

Heat input in kJ/inch is calculated:	In kJ/mm=
<u>Voltage x Amperage x 6</u> Travel Speed (inch/minute) x 100	<u>Volt age x Amperage x 3.6</u> Travel Speed (mm/s)

2. Interpass Temperature

A low interpass temperature is important. Stay below 200°F (100°C). Use water cooling if necessary (see VIII B4).

3. Preheat

RA X should NOT be preheated, beyond that necessary to dry it, that is, warm to the touch.

Preheating retards the cooling rate of a weld. Unlike carbon steel welds which may crack if cooled too quickly, nickel alloy welds actually require a rapid cool. This minimizes the time spent at the very high temperatures where these alloys are sensitive to hot tearing. Nickel alloys do not harden when the weld cools quickly.

4. Cooling

Auxiliary cooling methods may be used between weld passes to speed up the overall welding operation, providing they do not introduce contaminants that will remain in the joint. Examples of contaminants are: oil from a shop air line; grease or dirt from soiled, water soaked rags; or mineral deposits from hard water used to cool the weld joint. The safest way to maintain a low interpass temperature is to allow the assembly to cool naturally.

If necessary, spray bottles of demineralized water may be used to cool the weld between passes. Do not use tap water, as mineral deposits will contaminate the weld. No wet rags. Of course, the weld bead must be completely dry before the next pass.

VIII. WELDING

C. Weld Fillers

RA X alloy is normally welded with matching bare wire or covered electrodes.

Specifications

RA X bare wire AMS 5798	AWS A5.14/SFA-5.14 ERNiCrMo-2
RA X covered electrodes AMS 5799	AWS A5.11/SFA-5.11 ENiCrMo-2

Specified Chemistry Range,

RA X bare welding wire and covered electrodes

C	Mn	Si	P	S	Cr	Co	Mo	W
0.05	1.00	1.00	0.040	0.030	20.50	0.50	8.00	0.20
0.15	max	max	max	max	23.00	2.50	10.00	1.00

Cu	Other Elements Total	Fe	B	Ni
0.50	0.50	17.00	0.010	bal.
max	max	20.00	max	

VIII. WELDING

D. Surface Cleanliness

1. Shop dirt, oil, grease, cutting fluids, forming lubricants, etc, should be removed from the welding surface and an area two inches wide on each side of the joint by vapor degreasing or cleaning with a suitable agent.

2. Contamination by low melting metals is a cause of HAZ (heat affected zone) and weld bead cross cracking in austenitic alloys. Such contaminates include, but not are necessarily limited to, zinc, copper, aluminum and lead.

   Zinc contamination may arise from the widespread use of metallic zinc paint on steel structural members. Accidental overspray onto nearby RA X could result in unfortunate weld cracking.

   Sheet metal formed in Kirksite™ (zinc alloy) dies should be cleaned of all smeared-on zinc alloy.

   Copper from the copper back-up is a frequent (but not always recognized) cause of HAZ cracks in nickel alloys. The cracking usually becomes less severe as hold-down pressure (restraint) is reduced. Traces of copper too faint to be visually apparent can crack austenitic stainless steels, nickel alloys and cobalt alloys.

   A simple means of detecting trace copper is by the use of Cuprotesmo™ copper test paper, available as Product No. 90601 from Gallard-Schlesinger Industries, Inc. 584/G Mineola Ave, Carle Place, New York 11514-1731, U.S.A. PHONE: 516-333-5600 FAX: 516-333-5628.

   Chromium plating the copper back-up bar can avoid the nuisance of copper contamination cracking.

E. Weld Joint Designs and Procedures

1. Introduction

   RA X alloy wire and covered electrodes flow about like stainless fillers. The arc will not penetrate RA X base metal nearly so well as carbon steel. Therefore in order to obtain full penetration joints it is important to leave a root gap, and to bevel one or both sides of the joint in any plate thickness. This permits the weld metal to be laid in, rather than "burnt in," and allows proper electrode manipulation.

VIII. WELDING

E. Weld Joint Designs and Procedures

2. Root Passes

A sound root pass is critical to the entire weld. An undetected root crack will usually propagate outward through all subsequent filler passes. This can make weld repair a very time consuming matter.

It is good practice to liquid penetrant inspect the root pass for soundness, before proceeding with the filler passes. Test methods are described in ASTM Standards Volume 03.03, Nondestructive Testing, and include E 165 and E 1220.

The back side of all GTAW or GMAW root passes should be protected by 100% welding grade argon.

Shielded Metal Arc (SMAW) root passes are acceptable when the root side is accessible so that it may be backgouged to sound metal and rewelded.

Making a root pass using covered electrodes when that root cannot be gouged and rewelded is bad practice. In high temperature service that rough, scaled root is likely to collect whatever hot corrosive particles go by. Any remaining weld flux is also corrosive at red heat.

3. Joint Details

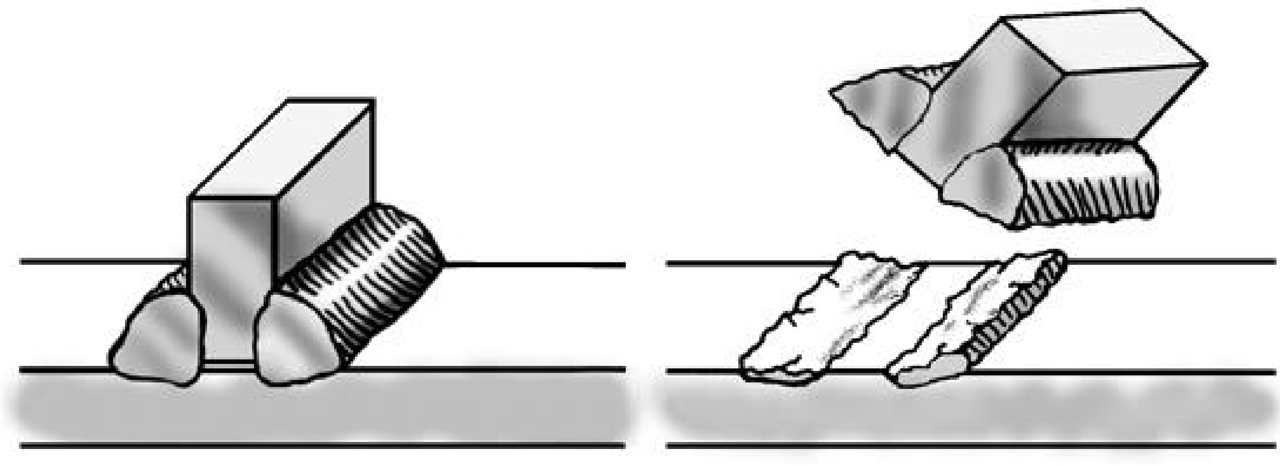
a. It is good practice to use the ASME Boiler and Pressure Vessel rules for such operations as joint design of head attachment to shell, butt welding plates of unequal thickness and welding of nozzles and other connections into heads and shells.

b. For high temperature or cyclic service it is important that welds be full penetration joints. INADEQUATE PENETRATION IS THE MOST COMMON CAUSE OF WELD FAILURES IN HIGH TEMPERATURE SERVICE.

VIII. WELDING

E. Weld Joint Designs and Procedures

3. Joint Details

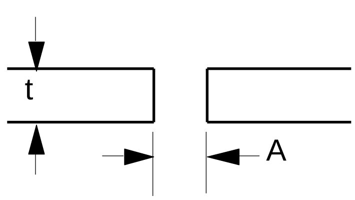


This un-welded cavity acts as a crack starter. Repeated thermal expansion and contraction will cause cracks to grow out through the weld.

Until it breaks apart completely.

4. Joint Designs

JOINT DESIGN 1. Square Butt Joint



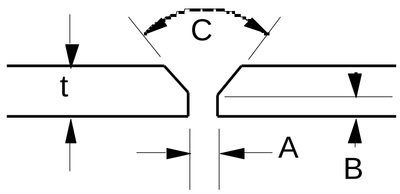
Maximum t = 1/8" (3.2 mm)
Gap A = 1/16" Minimum, 3/32" Maximum (1.6, 2.4 mm)

VIII. WELDING

E. Weld Joint Designs and Procedures

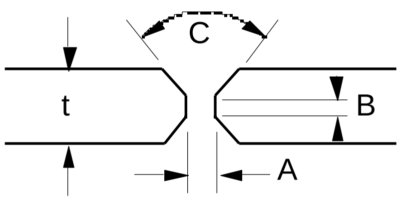
4. Joint Designs

JOINT DESIGN 2. Single "V" Joint



Maximum t = 1/2" (13 mm)
Gap A = 1/16" Minimum, 1/8" Maximum (1.6, 3.2 mm)
Land B = 1/16 to 3/32" (1.6 to 2.4 mm)
Angle C = 60 - 75°

JOINT DESIGN 3. Double "V" Joint



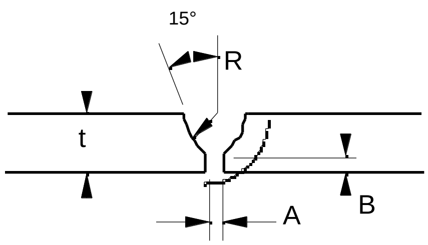
Gap A = 1/16" Minimum, 1/8" Maximum (1.6, 3.2 mm)
Land B = 1/16 to 3/32" (1.6 to 2.4 mm)
t = 1/2" (13 mm) or greater
Angle C = 60 - 75°

VIII. <u>WELDING</u>

E. Weld Joint Designs and Procedures

4. Joint Designs

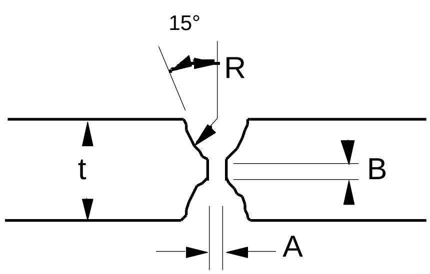
JOINT DESIGN 4. Single "U" Joint



Gap A = 1/16" Minimum, 1/8" Maximum (1.6, 3.2 mm)
Land B - 1/16 to 3/32" (1.6 to 2.4 mm)
Radius R - 3/8" (9.5 mm) Minimum

for single groove welds on heavy plate thicker than 3/4 inch (20 mm). Reduces the amount of time and filler metal required to complete the weld.

JOINT DESIGN 5. Double "U" Joint



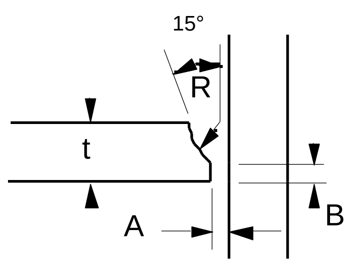
Gap A = 1/16 to 1/8" (1.6 to 3.2mm)
Land B = 1/16 to 3/32" (1.6 to 2.4 mm)
Radius R = 3/8" (9.5 mm) Minimum
Minimum t = 3/4" (20 mm)

VIII. WELDING

E. Weld Joint Designs and Procedures

4. Joint Designs

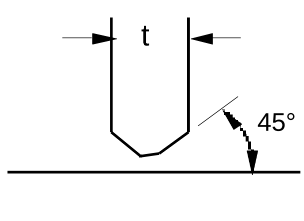
JOINT DESIGN 6. "J" Groove Joint



Gap A = 1/16 to 1/8" (1.6 to 3.2 mm)
Land B - 1/16 to 3/32" (1.6 to 2.4 mm)
Radius R - 3/8" (9.5 mm) Minimum

For single groove welds on plates thicker than 3/4 inch (20 mm). Reduces the amount of time and filler metal required to complete the weld.

JOINT DESIGN 7. "T" Joint



t = greater than 1/4" (6 mm)
For joints requiring maximum penetration.
Full penetration welds give maximum strength and avoid potential crevices.

VIII. WELDING

F.Welding Processes

RA X alloy has been welded by SMAW (covered electrodes), GTAW (TIG, or Heliarc®), GMAW (MIG) in both short-circuiting arc and spray-arc transfer modes, PAW (plasma) and by Resistance Welding. At this time we have no experience with SAW (submerged arc welding) RA X.

1. Shielded Metal Arc Welding (SMAW)

a. Current

RA X electrodes (AMS 5799, AWS A5.11 ENiCrMo-2) are AC/DC titania type electrodes. They can be used with either direct current (DC) or alternating current (AC). However the preferred current is DCRP (electrode positive).

b. Technique

Use stringer beads in the flat position. A slight weave, not exceeding three times the electrode diameter, is acceptable. Some weaving is unavoidable in vertical welds.

Arc length should be as short as possible to minimize loss of alloying elements through the arc. A "long arc," or increased gap between electrode and workpiece, may result in weld porosity and oxide inclusions. The electrode is generally directed back toward the molten puddle (backhand welding) with about a 20 to 40 degree drag angle.

c. Slag Removal

The fluoride content of welding fluxes renders them extremely corrosive at high temperatures, both in oxidizing and in reducing environments. All flux or slag should be completely removed before exposing the weldment to high temperature service conditions.

d. Electrode Care and Storage

RA X covered electrodes are supplied in sealed containers to prevent absorption of moisture. Once the container has been opened it is good practice to store these electrodes at 250 - 400°F (120 - 205°C) in an electric oven.

Electrodes which have absorbed excess moisture may be reclaimed by heating two to three hours at 600 - 700°F (315 - 370°C).

VIII. WELDING

F.Welding Processes

1. Shielded Metal Arc Welding (SMAW)

d. Electrode Care and Storage, continued

Moisture in the electrode coating may cause undesirable arc characteristics and is the most likely cause of weld porosity.

e. Amperage

The ampere setting suggested for each particular electrode will serve as a guide. Deviations from the suggested settings may be desired based upon speed of travel, depth of penetration, or welding position.

Some power sources do not give an output corresponding to the dial setting. The proper ampere setting may be obtained in the following manner:

Set the machine approximately at the required current value and make a run with the shortest arc possible. If the arc is very unstable, increase the current until a steady arc is obtained.

However, if the electrode becomes red hot when only about 1 - 1/2" (40 mm) remains, the current should be reduced until there is no visible evidence of heat through the coating of the unconsumed portion of the electrode. Lower amperage is possible with direct current (DC) than with a alternating current (AC).

The current should be kept at the lowest value that will maintain a steady, stable arc.

Typical Parameters, flat position:

Electrode Diameter inches (mm)	Welding Current (DCRP; electrode positive) amperes	Voltage
3/32 (2.4)	55-75	22-24
1/8 (3.2)	80-100	22-24
5/32 (4.0)	125-150	22-25

VIII. WELDING

F.Welding Processes

2. Gas Tungsten Arc Welding (GTAW)

In sheet gages RA X may be autogenous GTAW welded if desired.

2% thoriated tungsten electrodes (AWS EWTh-2) are used, with direct current straight polarity (electrode negative). For good arc control, grind the electrode tip to a 30 to 60 degree point, with a small flat at the tip. Grind lines should be parallel to the electrode, not circumferential. Finish grind on a 120 grit wheel. Adjust the arc on clean scrap metal, with no scale.

Typical GTAW Parameters

Joint Thickness, inch (mm)	Tungsten Electrode and Filler Wire dia, inch (mm)	Welding * Current, amps	Arc Voltage, volts
1/32 - 1/16 (0.8-1.5	1/16 (1.5)	15-60	9-12
1/16 - 1/8 (1.5-3)	1/16 or 3/32 (1.5 or 2.4)	50-95	9-12
1/8 - 1/4 (3-6)	3/32 or 1/8 (2.4 or 3.2)	75-130	10-13
greater than 1/4 (6)	3/32 or 1/8 (2.4 or 3.2)	95-150	10-13

*** Direct Current Straight Polarity (electrode negative)**

Argon is the normal shielding gas for manual welding. In automatic welding, helium may be added to the argon shielding gas to increase heat input and travel speed. Argon-helium mixtures are not practical for manual GTAW.

Purge gas should be 100% welding grade argon, or an argon-helium mix. Non-aerospace applications may also use dry nitrogen purge gas.

VIII. WELDING

F. Welding Processes

3. Gas Metal Arc Welding (GMAW)

RA X is commonly welded in the short circuiting-arc, pulsed-arc and spray-arc transfer modes.

a. Shielding Gases

The most common gases for short-arc welding are 75%Ar 25%He, and 90%He 7 - 1/2%Ar 2-1/2CO_2. Two of the newer cylinder gases may be advantageous. One for short-arc is 68%Ar 30%He 2%CO_2. The other, useful over a range of transfer modes is 81%Ar 18%He 1%CO_2.

Gases for pulsed-arc transfer include 100%Ar, 75%Ar 25%He or 81%Ar 18%He 1%CO_2.

Spray-arc transfer requires (at reasonable voltages) 80% or more argon in the shielding gas. Preferred gases are 100%Ar or 81%Ar 18%He 1%CO_2.

DO NOT EVER USE 95%Ar 5%O_2 OR 75%Ar 25%CO_2 SHIELDING GAS WITH RA X bare welding wire.

b. Short Circuiting Arc Transfer

The short-arc mode gives low heat input and a reinforced bead. Although commonly used for light gage work, it may be used with restrained joints or heavy plate to maximize resistance to hot cracking. Starts and stops should be ground to avoid lack of fusion defects (true also of stainless, and of carbon steel, when short-arced). The short-arc transfer mode is useful in all welding positions.

VIII. WELDING

F. Welding Processes

3. Gas Metal Arc Welding (GMAW)

b. Short Circuiting Arc Transfer

Typical parameters, flat position.

Wire dia, inch (mm)	DCRP Current amperes	Voltage
0.035 (0.9)	70 - 90	17 - 20
0.045 (1.14)	100 - 160	19 - 22

c. Pulsed-Arc Transfer

Pulsed-Arc offers the deposition rate and wetting advantages of spray-arc but with much lower heat input. It is an excellent choice for heat resistant alloy fabrication, and may be used in all welding positions.

Typical parameters, 75Ar 25He, fixed frequency pulse mode (60 CPS)

Wire dia, inch (mm)	Amperes	Peak	Volts
0.045 (1.14)	120 - 150	250 - 300	18 - 20

d. Spray-Arc Transfer

The spray transfer mode is accompanied by relatively high heat input, a stable arc and high deposition rates. Spray-arc welding is generally limited to the flat position.

Typical parameters, 100% Argon 30-32 volts.

Wire dia, inch (mm)	Current, DCRP, for spray transfer amperes
0.035 (0.9)	160 - 220
0.045 (1.14)	180 - 240

These currents are approximate, and may vary depending upon individual welding machine and choice of shielding gas. For best resistance to hot cracking in highly restrained joints use the lowest current that will still give a spray-arc mode.

VIII. WELDING

F.Welding Processes

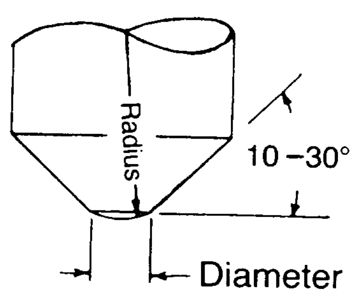
4. Plasma Arc Welding (PAW)

RA X may be welded by the plasma arc process. No further detail available. The use of filler metal, so far as possible with PAW, is advised.

5. Resistance Welding

Spot and seam welding parameters for RA X may differ slightly from those used with stainless such as 316L. RA X typically has about 50% higher yield strength than 316L and about 15% higher electrical resistivity. Electrode force, welding current and time, and electrode tip contours may all need to be modified accordingly.

A restricted-dome electrode is suggested for spot welding. Average dome radius may be 3 inch (75 mm) for material up to 11 gauge (3 mm). For a larger nugget size in material, 16 to 11 gauge (1.6 to 3 mm), a 5 to 8 inch (125 to 200 mm) radius dome is sometimes preferred.



In seam welding heat time should be adjusted to ensure that the wheel maintains pressure until the weld nugget has solidified, to avoid porosity and cracking. Likewise cool time should be sufficient that welded areas are not remelted.

VIII. WELDING

F. Welding Processes

6. Submerged Arc Welding (SAW)

Rolled Alloys has no direct experience with submerged arc welding. We suggest you take precautions to avoid hot cracking from this inherently high heat input process. Before any attempt is made to SAW alloy RA X in production the process should be qualified on the thickest plate to be fabricated. The smaller diameter wires are preferred.

If sound welds are to be made, it is important to use a highly basic flux. Adjust the parameters to deposit a reinforced bead contour and keep the interpass temperature below 200°F (100°C). Heat input should be held under 40 kilojoule per inch (1.5 kJ/mm).

Suggested fluxes include Avesta® Flux 803, Hobart® RECORD NiCrW or Lincoln® Electric's Blue Max 2000. Absolutely do not attempt to use acid fluxes meant for stainless steel.

Typical SAW Parameters

Wire Size, inch (mm)	DCRP Current amperes	Voltage	Wire Stickout, inch (mm)
0.045 (1.14)	150-225	25-28	1/2 (13)
0.062 (1.57)	180-250	25-28	3/4 (19)

Travel speed 8 - 12 inch/minute (200 - 300 mm/min)

Flux must be dry. Moisture absorption by flux during storage is the most likely cause of porosity in SAW. RECORD NiCrW which has absorbed moisture may be restored by heating one hour minimum at 750°F (400°C). Avesta Flux 803 may be redried by heating two hours minimum at 660°F (350°C). Either flux should be mixed once during the heating period to ensure uniform drying.

VIII. WELDING

G. Dissimilar Metal Welds

Considerations in selecting a filler metal for dissimilar metal weld joints include the expected service conditions at the joint, relative thermal expansion coefficients and metallurgical compatibility of weld and base metal.

This suggested list of weld filler materials is based on welding knowledge and experience rather than laboratory work. Final selection should be approved by the end user and weld procedures qualified by the fabricator.

For Joining RA X to:	Suggested Filler Metals
Carbon steel*; ferritic stainless steels such as 409, 439, or 446; austenitic-ferritic duplex stainless steels such as 2205, 2507, Ferralium® 255	RA 182 (ENiCrFe-3) covered electrodes Hastelloy® S (AMS 5838) bare wire RA82 (ERNiCr-3) bare wire
Austenitic stainless steels 304, 316, 321, 347, 309, RA 253 MA® and 310; nickel alloy RA330®	RA330-04-15 (UNS No. W88334) covered electrodes RA330-04 (UNS No. N08334) bare wire RA X (ERNiCrMo-2, AMS 5798) bare wire
RA85H®	Haynes® 556 (AMS 5831) bare wire
RA601	RA X bare wire RA333-70-16 (UNS No. W86333) covered electrodes RA333 (UNS No. N06333) bare wire
RA600	RA 182 covered electrodes RA82 bare wire RA X (AMS 5798) bare wire
RA 353 MA®	RA 353 MA-15 covered electrodes RA 353 MA bare wire RA X (AMS 5798) bare wire
RA625	RA112 (AWS ENiCrMo-3) covered electrodes RA625 (AWS ERNiCrMo-3, AMS 5837) bare wire RA X (AMS 5799) covered electrodes RA X (AMS 5798) bare wire

* Carbon steel MUST be ground to bright metal, or nickel alloy weld wire simply will not stick to it. A "mill finish" is not acceptable. All rust, blue-black hot rolling scale and paint must be removed before using nickel alloy weld fillers on carbon steel. Covered electrodes are somewhat more tolerant than bare wires, with respect to cleanliness.

VIII. WELDING

G. Dissimilar Metal Welds, continued

For Joining RA X to:	Suggested Filler Metals
RA333®	RA333-70-16 covered electrodes RA333 bare wire RA X (AMS 5798) bare wire
Cast heat resistant alloys HH, HK, HT, HP	RA330-80-15 (UNS No. W88338) covered electrodes Hastelloy® S (AMS 5838) bare wire
AL-6XN®	RA 112 covered electrodes RA 625 bare wire
Alloys C-276, C-22, 59	C-22 (AWS ENiCrMo-10) covered electrodes C-22 (AWS ERNiCrMo-10) bare wire
Haynes® 230, alloy 617	RA X (AMS 5798) bare wire 230-W™ (AWS ERNiCrWMo-1) bare wire Hastelloy S (AMS 5838) bare wire
Cobalt alloys L-605 (alloy 25) and 188	Haynes 556 (AMS 5831) bare wire RA X (AMS 5798) bare wire
* RA718, X-750, Waspaloy®, René 41®	Hastelloy S (AMS 5838) bare wire RA W (AMS 5786) bare wire

* These age hardening grades have fabrication characteristics completely outside the scope of this bulletin. Do become familiar with their welding requirements before making any weldment incorporating such alloys.

VIII. WELDING

H. Controlling Distortion

RA X alloy has about 15% higher coefficient of thermal expansion than does carbon steel, but only about one fourth the thermal conductivity of steel. This combination naturally increases welding stresses and results in distortion in welded structures.

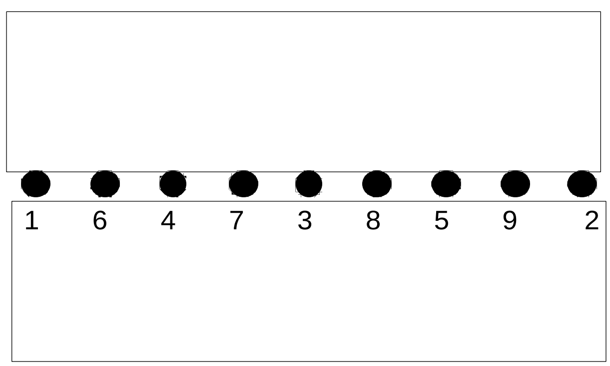
Heat treatment to relieve welding stresses in stainless or nickel alloys is usually ineffectual, impractical or downright harmful.

Proper fixturing, joint design, staggered weld bead placement or weld sequence and controlling heat input can all serve to minimize distortion.

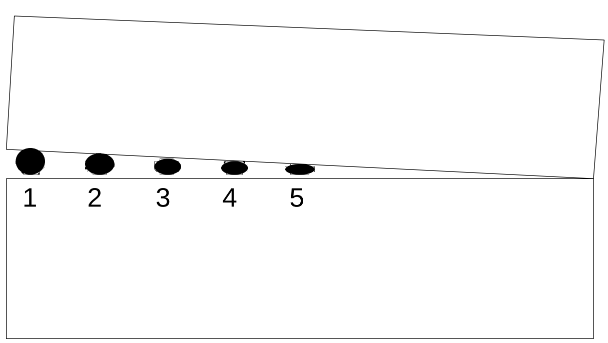
The following are general suggestions:

2. Sequence

   a. Tacks should be sequenced.



If the tacks are simply done in order from one end, the plate edges close up.

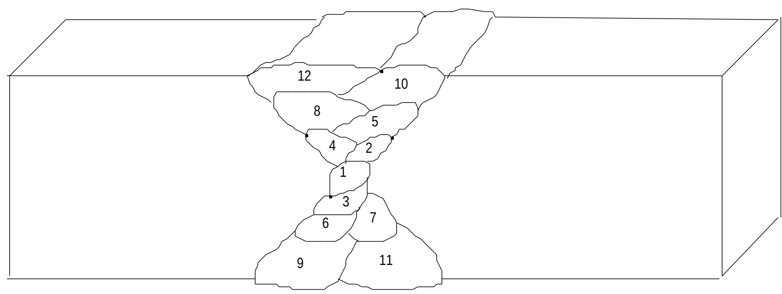


VIII. WELDING

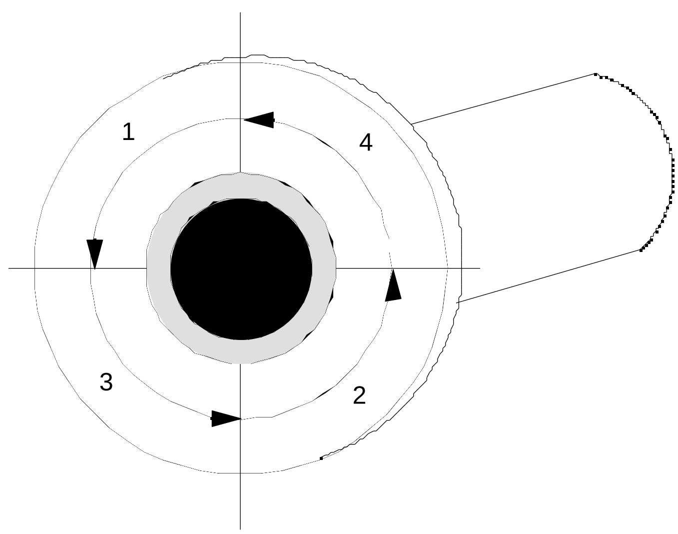
H. Controlling Distortion

2. Sequence

b. Weld runs should be done symmetrically about the joint's center of gravity to balance stresses +



double V - preparation



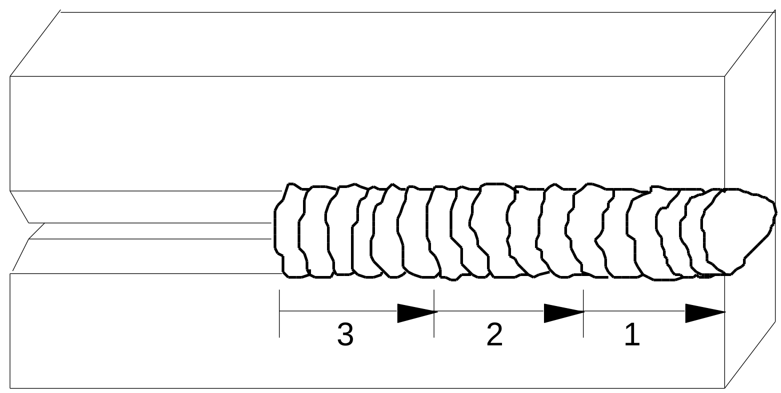
flange to cylinder

VIII. WELDING

H. Controlling Distortion

3. Heat Balance +

Back step welding is helpful



* from <u>Avesta Handbook for the Welding of Stainless Steel,</u> Inf. 8901, Avesta Sheffield Welding AB, Avesta Sweden

\+ from <u>Sandvik Welding Handbook,</u> by Berthold Lundqvist, Sandvik AB, Sandviken Sweden

VIII. WELDING

H. Controlling Distortion

4. Heat Input

Heat into the workpiece is controlled by welding current, arc voltage, travel speed and the specific welding process used. For the same amps, volts and speed submerged arc welding (SAW) transfers the most heat, manual arc (SMAW) and gas metal arc (GMAW) with argon next and roughly equivalent, while gas tungsten arc welding (GTAW) can put the least heat into the work.

Reducing heat input reduces the stresses and distortions from the welding operation.

VIII. WELDING

I. Weld Filler Consumption

Filler metal requirements range from about 2 - 1/2 to 5 percent of the weight of plate involved in a fabrication. Estimated weight of covered electrodes and spooled wire for various joint configurations is given below.

1. U. S. Customary Units

		APPROXIMATE WEIGHT, IN POUNDS, OF		
JOINT DESIGN	PLATE THICKNESS, INCHES	METAL DEPOSITED PER LINEAL FOOT WITH REINFORCEMENT	ELECTRODES REQUIRED (A)	GMAW WIRE REQUIRED (B)
SINGLE FILLET	1/8	0.032	0.064	0.038
	3/16	0.072	0.144	0.085
	1/4	0.13	0.26	0.15
	3/8	0.29	0.58	0.34
	1/2	0.52	1.03	0.60
	5/8	0.80	1.61	0.94
"V" GROOVE	1/4	0.37	0.73	0.43
	3/8	0.62	1.23	0.73
	1/2	0.85	1.7	1.00
DOUBLE "V" GROOVE	1/2	0.77	1.53	0.90
	5/8	0.95	1.90	1.12
	3/4	1.32	2.63	1.55
	1	1.83	3.65	2.16

(A) Assumes 50% deposition efficiency

(B) Assumes 85% deposition efficiency

VIII. WELDING

I. Weld filler consumption, continued

2. SI Units

		Approximate Weight, in Kilograms, of		
Joint Design	Plate Thickness, mm	Metal Deposited Per Lineal Meter, With Reinforcement	Covered Electrodes Required A	GMAW Wire Required B
Single Fillet	3	0.043	0.087	0.051
	5	0.120	0.24	0.14
	6	0.173	0.35	0.20
	8	0.308	0.61	0.36
	10	0.481	0.96	0.57
	12	0.692	1.38	0.81
	16	1.23	2.46	1.45
	20	1.92	3.84	2.26
V Groove	6	0.513	1.03	0.60
	8	0.729	1.46	0.86
	10	0.960	1.92	1.13
	12	1.19	2.38	1.40
Double V Groove	12	1.06	2.12	1.25
	16	1.79	3.58	2.11
	20	2.01	4.02	2.36
	25	2.68	5.36	3.15

A Assumes 50% deposition efficiency

B Assumes 85% deposition efficiency

IX. BRAZING

RA X components for gas turbine engines are commonly joined by brazing with nickel alloy filler metals.

Some items to consider are:

Cleanliness — **Not only oxide scales but all traces of grease, oil, marking pencil or residual dye or fluorescent penetrant inspection fluids must be removed, or they may interfere with braze flow.**

Atmosphere — **Vacuum or dry hydrogen, dew point -60°F (-51°C) or lower, are used. Graphite fixturing in hydrogen atmospheres may transfer carbon to the work unless protected.**

Joint fit-up — **Suggested joint gaps are the gaps AT TEMPERATURE. When brazing dissimilar metals take into account thermal expansion coefficients when calculating gap at the brazing temperature.**

Repair cycles — **With nickel-silicon-boron braze fillers diffusion into the base metal raises the subsequent remelt temperature of the joint.**

IX. BRAZING, continued

Some commonly used high temperature braze filler metals for RA X include:

Specifications AMS	AWS	Trade or Common Name	Brazing Range ºF	ºC	Suggested Braze Temp ºF	ºC	Joint Gap inch	mm
4787	BAu-4	Permabraze® 130	1745	950	1800	980	0.0015	0.04
		82Au-18Ni	1850	1010	minimum		0.003	0.08
4777	BNi-2	Nicrobraz® L.M.	1850	1010	1900	1040	0.001	0.025
		Coast Metal® 53	2150	1175			0.004	0.10
		MBF 20*						
4778	BNi-3	Nicrobraz 130	1850	1010	1900	1040	from contact to:	
		Coast Metal 52	2150	1175			0.002	0.05
		MBF 30						
4779	BNi-4	Nicrobraz 135	1950	1065	2050	1120	0.002	0.05
		Coast Metal 50	2150	1175			0.004	0.10
4782	BNi-5	Nicrobraz 30	2100	1150	2175	1190	0.001	0.025
			2200	1205			0.004	0.10

* METGLAS® Brazing Foil

SUGGESTED READING

RA X data and other fabrication information available from Rolled Alloys include:

Bulletin No	Title	Pages
152	Aircraft and Aerospace Heat Resistant Alloys	17
201	Welding RA330	12
203	Fabrication Procedures for Rolled Alloys AL-6XN®	58
205	RA320LR Welding Materials	2
207	RA330® Heat Resistant Alloy Fabrication	42
208	RA85H® Heat Resistant Alloy Fabrication	27
209	RA 353 MA® Fabrication	8

General heat resistant alloy welding information is available in:

R. J. Castro & J. J. deCadenet, "Welding Metallurgy of Stainless and Heat-Resisting Steels," ISBN 0 521 20431 3, Cambridge University Press 1975.

"Welding Dissimilar Metals" ed. N. Bailey, The Welding Institute, 1986.

T. G. Gooch "Solidification Cracking of Austenitic Stainless Steel" pp 31-40 Weldability of Materials, ed. R. A. Patterson and K. W. Mahin, ISBN: 0-87170-401-3 ASM International 1990.

"Arc Welding of Nickel Alloys" pp 436-445, Metals Handbook Ninth Edition Volume 6 Welding, Brazing and Soldering, ASM International.

Resistance Welding Manual, available from Resistance Welder Manufacturers' Association, 1900 Arch Street, Philadelphia Pennsylvania 19103 FAX 215-564-2175

S. J. Matthews, M. O. Maddock & W. F. Savage "How Copper Surface Contamination Affects Weldability of Cobalt Superalloys," Welding Journal, May 1972.

E. F. Nippes & D. J. Ball "Copper-Contamination Cracking: Cracking Mechanism & Crack Inhibitors," pp 75S-81S, Welding Research Supplement March 1982.

William G. Ashbaugh "Liquid Metal Embrittlement-Part II" pp 88-89, Materials Performance February 1993.

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