# AL-6XN® alloy FABRICATION

Technical Paper

Flue gas duct lining, 14 gage AL-6XN

**CONTENTS**

## DESCRIPTION AND SPECIFICATIONS

AL-6XN alloy is a high molybdenum superaustenitic stainless with outstanding resistance to chloride pitting, crevice corrosion and stress corrosion cracking. In order to maintain this corrosion resistance in weldments, an overmatching 9% Mo filler is used.

**SPECIFICATIONS:**

UNS N08367

**AL-6XN Chemistry Range**

| Ni | Cr | Mo | C | N | Mn | Si | P | S | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| 23.50 | 20.00 | 6.00 | 0.030 | 0.18 | 2.00 | 1.00 | 0.040 | 0.030 | .075 | remainder |
| 25.50 | 22.00 | 7.00 | max | 0.25 | max | max | max | max | max | |

**Minimum Mechanical Properties**

| | Ultimate Tensile,psi | 0.2% Yield Strength,psi | Elongation % |
|---|---|---|---|
| Sheet under 3/16" thick | 104,000 | 46,000 | 30 |
| Plate 3/16" through 3/4", welded tube | 100,000 | 45,000 | 30 |
| Plate over 3/4", welded pipe, forgings, bar, rod | 95,000 | 45,000 | 30 |

1999 Agenda ASME Section VIII, Div. 1, design stresses, ksi:

| Temperature °F | 200 | 300 | 400 | 500 | 600 | 650 | 700 | 800 |
|---|---|---|---|---|---|---|---|---|
| Plate 3/16-3/4", | 28.6 | 27.0 | 25.8 | 25.0 | 24.5 | 24.3 | 24.1 | 23.8 [A] |
| Welded tube | 26.2 | 23.8 | 21.9 | 20.5 | 19.4 | 19.0 | 18.6 | 18.0 |
| Welded pipe, | 25.3 | 23.9 | 22.8 | 22.1 | 21.7 | 21.5 | 21.3 | 21.1 [A, B] |
| Welded tube | 22.7 | 20.7 | 19.1 | 17.8 | 16.9 | 16.5 | 16.2 | 15.6 [B] |

[A] Note G5: Due to the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. The stress values in this range exceed 66-2/3% but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

[B] Note G14: A factor of 0.85 has been applied in arriving at the maximum allowable stress values in tension for this material. Divide tabulated values by 0.85 for maximum allowable longitudinal tensile stress.

For external pressure design in Section VIII use Fig. NFN-12, of Section II, Part D. AL-6XN is listed as P No. 45 in Section IX.

Section IIB includes SB-688 plate, sheet & strip, SB-675 welded pipe, SB-676 welded tube, SB-691 rod, bar & wire, SB-462 forged pipe flanges, fittings and valves, SB-366 wrought nickel alloy welding fittings.

## FORGING

Heat AL-6XN uniformly to a starting temperature of 2275°F (1246C). Finish forging by 1850°F (1010C).

Heat treatment after forging is required to dissolve secondary phases and restore corrosion resistance. Anneal forgings 2100-2150°F (1149-1177C), water quench.

## COLD FORMING

AL-6XN alloy has good cold formability. Bending, drawing and pressing, and other forming operations that occur in the production of fabricated items are readily performed.

AL-6XN alloy plate can normally be press brake bent over a radius equal to the plate thickness. With sheared plate it is good practice to remove the shear burr, to avoid cracking. As with other austenitic stainless and nickel alloys, bending over a sharp male die may cause the material to crack.

Heat treatment after cold working operations is usually not required.

## MACHINING

AL-6XN is quite ductile in the annealed condition, but it work hardens more rapidly and requires more power to cut than do the plain carbon steels. Chips are stringy and tough. Approximate speeds for turning and milling are 70 sfm, and for drilling 50 sfm.

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.

Tools, either high speed steel or cemented carbide, should be sharp, and reground at predetermined intervals. 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. This is essential. 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.

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

## TUBE BENDING AND ROLLING

AL-6XN alloy tubes can be bent to a minimum bend radius of 1-1/2 times the tube outside diameter (O.D.). This is an inside radius of 1 times O.D., and a centerline-to-centerline leg spacing of 3 times O.D.

Unlike copper alloy or titanium tubes, AL-6XN alloy tubes may be rolled to the full thickness of the tubesheet. No provision need be made for staying back from the inside face of the tubesheet.

AL-6XN alloy tubes may be successfully expanded using 3, 4 or 5-roller expanders. Selection of the number of rolls is largely a matter of personal preference. However, 5-roller expanders tend to be more forgiving when operator skills vary.

## HEAT TREATMENT

If necessary, AL-6XN alloy is annealed after heavy cold work 2050-2150°F (1121-1177C), water quench. Slow cooling is not recommended, as this would reduce the alloy's corrosion resistance.

## DESCALING AND PICKLING

Heavy annealing or hot working scale may be removed by abrasive blasting followed by pickling in 4% nitric, 4% hydrofluoric acid solution for about 30 minutes at 120-140°F. Water containing less than 50 ppm chlorides is preferred for this solution.

Weld scale may be removed by stainless wire brushing, but this alone will leave the weldment with less than optimum corrosion resistance. Preferred treatment is blasting with 75-100 micron soda-lime glass beads. Alternately, wire brushed welds may be cleaned with a commercial nitric-hydrofluoric pickling paste.

## WELDING--FILLER METALS, HEAT INPUT

Al-6XN alloy must be welded with overalloyed filler metal in order for the joint to have corrosion resistance equivalent to the base metal. A nominal 9% molybdenum weld filler, such as ERNiCrMo-3 wire (alloy 625) or an ENiCrMo-3 electrode, is preferred. It is important that the root be gapped sufficiently that the weld bead is composed mostly of 9% molybdenum filler, without excessive dilution by AL-6XN base metal.

Heat input should be low to avoid hot cracking in the 625 weld bead. Preferably, stay below 40 kilojoule per inch and definitely below 50 kJ/in.

Heat input in kJ/inch is calculated:

$$\frac{\text{Voltage x Amperage x 6}}{\text{Travel Speed (inch/minute) x 100}}$$

Interpass temperatures should be kept below 300°F (150C). On highly restrained joints or heavy (over 1/2") plate, stay below 200°F (93C). Low interpass temperature reduces chances of nickel alloy weld bead solidification cracking.

The nickel alloy weld fillers used with AL-6XN give a more viscous weld pool than conventional stainless fillers. There is a temptation to raise welding current to improve fluidity, but this increases risk of hot cracking.

## COVERED ELECTRODES (SMAW)

Use stringer beads with ENiCrMo-3 covered electrodes in the flat position. A slight weave, not exceeding two times the diameter of the electrode, may be used. Weaving is unavoidable in vertical welds.

Maintain as short an arc length as possible. A "long arc" or increased gap between electrode and workpiece may result in weld porosity and excessive oxides in the weld. Avoid welding in the presence of direct drafts of air, wind or fans.

Remove all slag from each filler pass by use of chipping tools, fine grinding or stainless wire brushes. DO NOT USE CARBON STEEL WIRE BRUSHES. Steel particles will contaminate the weldment and likely initiate pits in chloride environments.

RA112 (ENiCrMo-3) covered electrodes must be kept dry to avoid porosity and undesirable arc characteristics. Store these electrodes in an electric oven at 225°F (107C). Electrodes which have absorbed excess moisture may be reclaimed by first heating two hours at 225°F (107C), followed by one hour at 600°F (316C).

**Typical SMAW Parameter**

| Electrode dia., inch | Direct Current Reverse Polarity, amperes | Voltage |
|---|---|---|
| 3/32 | 40-70 | 24 |
| 1/8 | 60-95 | 25 |
| 5/32 | 90-135 | 26 |

## GAS METAL ARC WELDING (GMAW)

Shielding gas is normally 100% welding grade argon having a nominal purity of 99.996% and a dew point of -77°F. Helium may be added if desired to flatten the bead contour. Argon - 25% helium is often used with pulsed arc or short-circuiting arc welding. Do not add any oxygen, carbon dioxide or nitrogen.

### Typical GMAW Parameters

#### Spray-arc transfer, 100% argon shielding at 35-55 cfh

| Wire dia., inch | Direct Current Reverse Polarity, amperes | Voltage |
|---|---|---|
| 0.035 | 180-220 | 28-34 |
| 0.045 | 200-260 | 28-34 |

Use the high end of range for heavy plate, 3/4" and over, which can act as a heat sink.

#### Pulsed-arc transfer, 75% argon 25% helium shielding gas, 120 pulse/sec

| Wire dia., inch | Direct Current, Reverse Polarity, amperes | Voltage |
|---|---|---|
| .045 | 150-165 | 20-21 |

## SUBMERGED ARC WELDING (SAW)

When sub-arc welding AL-6XN alloy, use a highly basic flux, non-chromium compensating, such as Avesta® Flux 805 or Böhler Thyssen's RECORD NiCrW. Do not use acid fluxes meant for 18-8 stainless. Average flux consumption about one pound per pound of wire. Flux must be dry. Flux 805 which has absorbed moisture may be restored by heating two hours minimum 660°F (350C). Mix the flux once during the heating period to ensure uniform drying.

### Typical SAW Parameters

| Wire size, Inch | DCRP Current amperes | Voltage | Wire Stickout,inch | Travel Speed inch/minute |
|---|---|---|---|---|
| . 045 | 150-225 | 25-28 | 1/2 | 8-12 |
| .062 | 225-300 | 25-28 | 3/4 | 8-12 |
| .094 | 275-350 | 25-28 | 1 | 8-12 |

## FLUX CORED ARC WELDING (FCAW)

ENiCrMo3T-1 gas shielded welding wire is used with 75% argon-25% $CO_2$ (C25) shielding gas. Wire feed rolls should be knurled. Use stringer beads with very little weave, to avoid trapping slag at bead edges.

### Suggested Welding Parameters

| Wire dia., inch | Wire Feed inch/min | Amperes, DCRP | Volts | Wire Stick-out, inch |
|---|---|---|---|---|
| .045 | 275-350 | 150-210 | 26-31 | 3/8-1/2 |

## GAS TUNGSTEN ARC WELDING (GTAW)

With GTAW, use straight stringer beads. Limit dilution of the weld bead by AL-6XN base metal, particularly in the root pass.

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. Use 1/2 inch minimum (No. 8) gas cup with gas lens. Shielding and purge gases normally 100% argon for manual welding.*

### Typical GTAW Parameters

| 2% Thoriated Tungsten Electrode dia., inch | Direct Current Straight Polarity (electrode negative), amps | Voltage |
|---|---|---|
| .040 | 25-80 | 10-14 |
| .062 | 50-145 | 12-16 |
| .094 | 135-235 | 12-16 |

* add 3-5% nitrogen when autogenously welding sheet gages.

## DISSIMILAR METAL WELDS

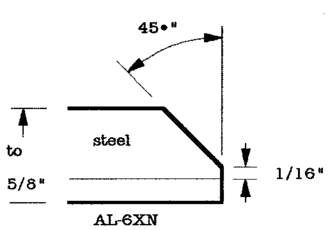
| **To join AL-6XN alloy to:** | **Suggested Filler Metal** |
|---|---|
| carbon steel,* | ERNiCr-3 (RA82) |
| 304, 316 stainless | ENiCrMo-3 (RA112), ERNiCrMo-3 (RA625) |
| duplex stainless (2205, 255, 2507) | ERNiCrMo-14 (686CPT)<br>ERNiCrMo-10 (C-22) |
| 317, 317LM, 904L, Alloy G, 20Cb-3® stainless, Alloy 625 | ENiCrMo-3 (RA112)<br>ERNiCrMo-3 (RA625) |
| Alloys C-276, C-22 | ERNiCrMo-4 (C-276)<br>ERNiCrMo-10 (C-22) |

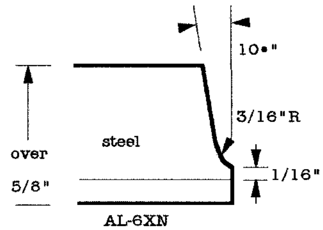
*Steel must be ground to bright metal. All rust, hot rolling scale and oil must be removed before welding.

## CLAD PLATE WELDING

AL-6XN may be clad to carbon and alloy steels such as A 282, A 514, A 516 and others. The steel side of the joint is welded with the filler metal and procedure appropriate to that steel. The AL-6XN side should be welded with at least two layers of ERNiCrMo-3 wire or ENiCrMo-3 electrodes.

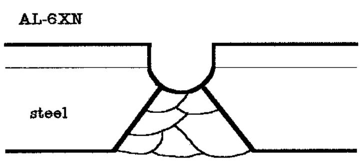
Prepare the joint with a minimum 1/16" land on the backing steel to minimize dilution from steel into the AL-6XN clad.

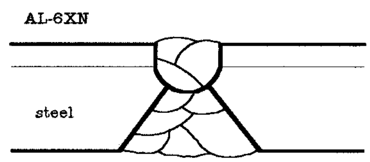



Tack the joint on the steel side using the same electrode as intended for the steel root bead. Finish welding the steel side.

Then back-gouge the AL-6XN clad side to sound metal. Width of the gouged groove should be 1/4" to 5/16" for plate to 1/2" thick. Groove width should be 3/8 to 1/2" for plate over 1/2" to 1" thick.



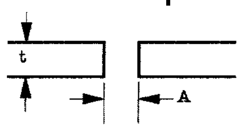




Weld the clad side with two or more layers of ERNiCrMo-3 weld wire or ENiCrMo-3 electrodes. Minimize dilution by using pulsed-arc GMAW (preferred), second choice FCAW or SMAW. A root pass with alloy C-22 wire or electrodes may be used, if desired, to counter-act dilution from the steel.

## WELD JOINT DESIGNS

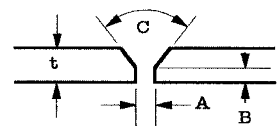
RA625 or RA112 nickel weld fillers flow more sluggishly than stainless. For this reason joints need to be more open at the root. A J- or U-preparation may be needed with RA625 where a V would suffice with ER 308 stainless. Avoid feather-edge roots--these promote high dilution and reduced corrosion resistance. The following are a few suggested joint designs, intended to achieve full penetration welds.

**JOINT DESIGN 1. Square Butt Joint**



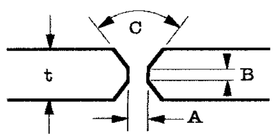

Maximum t = 1/8"
Gap A - 1/16" to 1/32"

**JOINT DESIGN 2. Single "V" Joint**



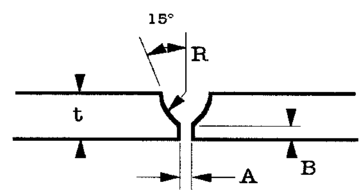

Gap A = 1/16" to 3/32"
Land B = 1/16" to 3/32"
Angle C - 60° - 75°

**JOINT DESIGN 3. Double "V" Joint**




Gap A = 1/16" to 1/8"
Land B = 1/16" to 3/32"
t = 1/2" or greater
Angle C = 60° - 75°

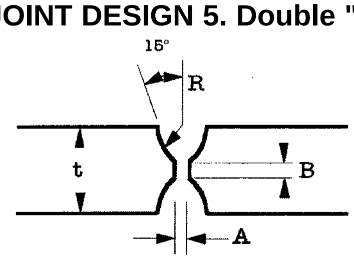
**JOINT DESIGN 4. Single "U" Joint**




Gap A = 1/16" to 1/8"
Land B = 1/16" to 3/32"
Radius R = 3/8" Minimum

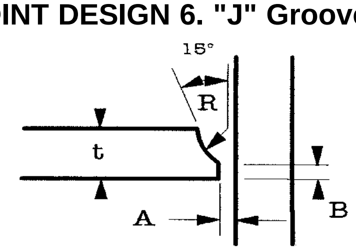
For single groove welds on heavy plate 3/4" and over. Reduces the amount of time and filler metal required to complete weld.

**JOINT DESIGN 5. Double "U" Joint**




Gap A = 1/16" to 1/8"
Land B = 1/16" to 3/32"
Radius R = 3/8" Minimum
Minimum t = 3/4"

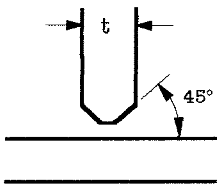
**JOINT DESIGN 6. "J" Groove Joint**




Gap A = 1/16" to 1/8"
Land B = 1/16" to 3/32"
Radius R = 3/8" Minimum

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

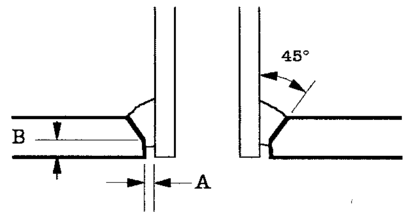
**JOINT DESIGN 7. "T" Joint**




t = greater than 1/4"

For joints requiring maximum penetration. Full penetration welds given maximum strength and avoid potential crevice corrosion sites.

**JOINT DESIGN 8. For Openings such as manways, viewports and nozzles.**




Gap A = 1/16" to1/8"
Land B - 1/16" to 3/32"

## QUALITY ASSURANCE

Fabrication quality is key to the successful applications of advanced nickel alloys. Users are strongly urged to have the potential fabricator develop weld procedures and to qualify them to ASME Standards. Qualifications should include the lightest gage sheet involved in the fabrication, as well as the heaviest plate gage.

Weld procedures should also be qualified for any dissimilar alloy weldments, such as to carbon steel, stainless or other nickel alloys.

Sub-contractors should be required to develop their own weld procedures to be approved by the end user.

Bulletin 1004 06/27/00



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