AL-6XN®
alloy

Features
- Excellent resistance to pitting and crevice corrosion in chloride solutions
- Practical immunity to stress corrosion in NaCl environments
- High strength and toughness

Applications
- Seawater heat exchangers
- Pulp bleaching plant washers, vats, press rolls and pipelines
- Scrubbers
- Chemical process tanks and pipelines
- Tall oil distillation columns and packing
- Reverse osmosis desalination equipment and pumps
- Offshore oil and gas production equipment

Chemical Composition, %

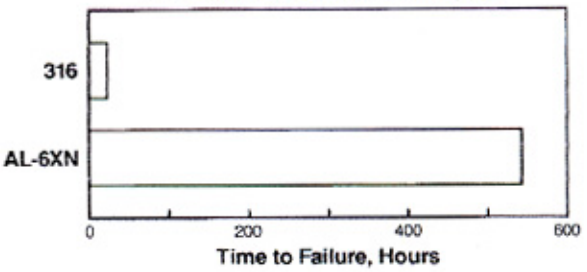
	Min.	Max.
Nickel	23.50	25.50
Chromium	20.00	22.00
Molybdenum	6.00	7.00
Carbon	—	0.03
Nitrogen	0.18	0.25
Manganese	—	2.00
Silicon	—	1.00
Phosphorus	—	0.040
Sulfur	—	0.030
Copper	—	0.75
Iron	Remainder	

Specifications
UNS N08367
ASME Section VIII, Division 1
For external pressure use Fig. NFN-12 of Section II, Part D.
Section III Division 1 Class 2 and 3 construction, Case N-438-2.
ASME Section IX, P No. 45
NACE MR0175

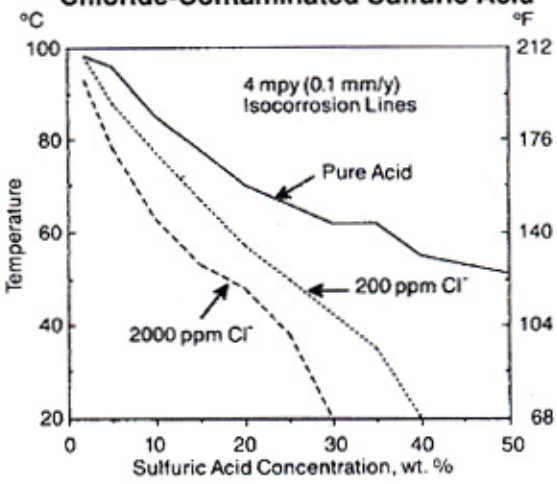
Performance Profile
AL-6XN alloy is a superaustenitic stainless with outstanding resistance to chloride pitting and crevice corrosion. The levels of chromium, molybdenum and nitrogen all serve to provide resistance to acidic, oxidizing chloride solutions previously achieved only by the nickel base alloys. High nickel (24%) and molybdenum (6.3%) contents make AL-6XN a useful engineering solution to the problem of chloride ion stress corrosion cracking.

Because of its nitrogen content, AL-6XN has greater tensile strength than common austenitic stainlesses, while retaining high ductility and impact strength. The ASME allowable stresses for AL-6XN are up to 75% higher than for 316L stainless, and more than twice those for the copper-nickel alloys.

Stress Corrosion Cracking Resistance, Boiling 42% $MgCl_2$



Isocorrosion Chloride-Contaminated Sulfuric Acid



AL-6XN®

Mechanical Properties

Representative Tensile and Impact Properties, Plate

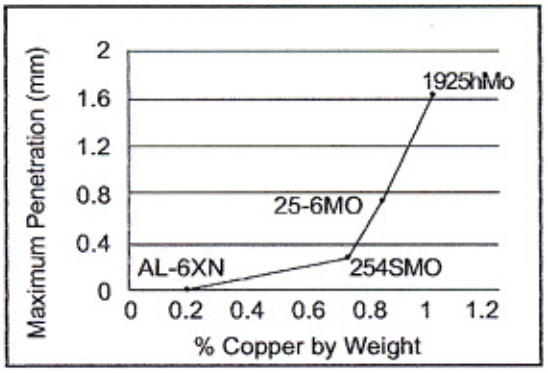
Temp °F	Ultimate Tensile Strength, psi	0.2% Yield Strength, psi	Elongation in 2" %	Charpy V-Notch Toughness ft-lb
-450	218,000	142,000	36	353 *
-320	196,000	107,000	49	85
-200	—	—	—	100
70	108,000	53,000	47	140
200	99,900	49,400	47	—
400	90,300	40,400	46	—
600	86,000	36,300	47	—
800	87,000	36,000	48	—
1000	83,600	33,900	50	—

*K_{1c}, ksi $\sqrt{inch}$

ASME Boiler and Pressure Vessel Code
Section II D
Maximum allowable design stresses, ksi, for welded construction

For Metal Temp Not Exceeding, °F	Maximum Allowable Stress Values, ksi: Welded pipe & tube under 3/16" wall	Plate forgings, bar, rod
100	24.3	27.1
200	24.3	27.1
300	23.0	25.7
400	22.0	24.6
500	21.3	23.8
600	20.8	23.3
650	20.7	23.1
700	20.5	22.9
750	20.4	22.8
800	20.2	22.6
NOTES:	G5, G14	G5

*** For welded pipe and tube, a joint efficiency factor of 0.85 must be applied.**



Effect of Copper content on crevice corrosion attack of 6% Mo alloys in natural seawater after removal of the original mill surface.

Physical Properties

Density lb/in³	Melting Range °F
0.291	2410-2540

Temp °F	Coefficient of Thermal Expansion*, in/in°F x 10^{-6}	Thermal Conductivity Btu·ft/ft²·hr·°F	Modulus of Elasticity Dynamic, psi x 10^6
70	—	6.7	28.3
200	7.9	7.5	27.4
300	8.3	8.1	–
400	8.4	8.7	26.1
600	8.6	10.0	24.8
700	8.7	10.6	—
800	8.8	11.2	23.4
1000	9.0	12.5	22.1
1200	9.3	13.9	—

* 70°F to indicated temperature.

Temperature for Initiation of Crevice Corrosion in 10% Ferric Chloride.

Alloy	Critical Crevice Corrosion Temp, °F	Pitting Resistance Equivalent (PRE) N
316L	27	23
825	27	30
317L	35	29
317LXN™	68	34
RA2205	68	37
E-BRITE®	75	29
G	86	43
AL-6XN®	110	48

(PRE) N = % Cr + 3.3% Mo + 30% N

Corrosion Rates in Boiling Organic Acids
mils per year

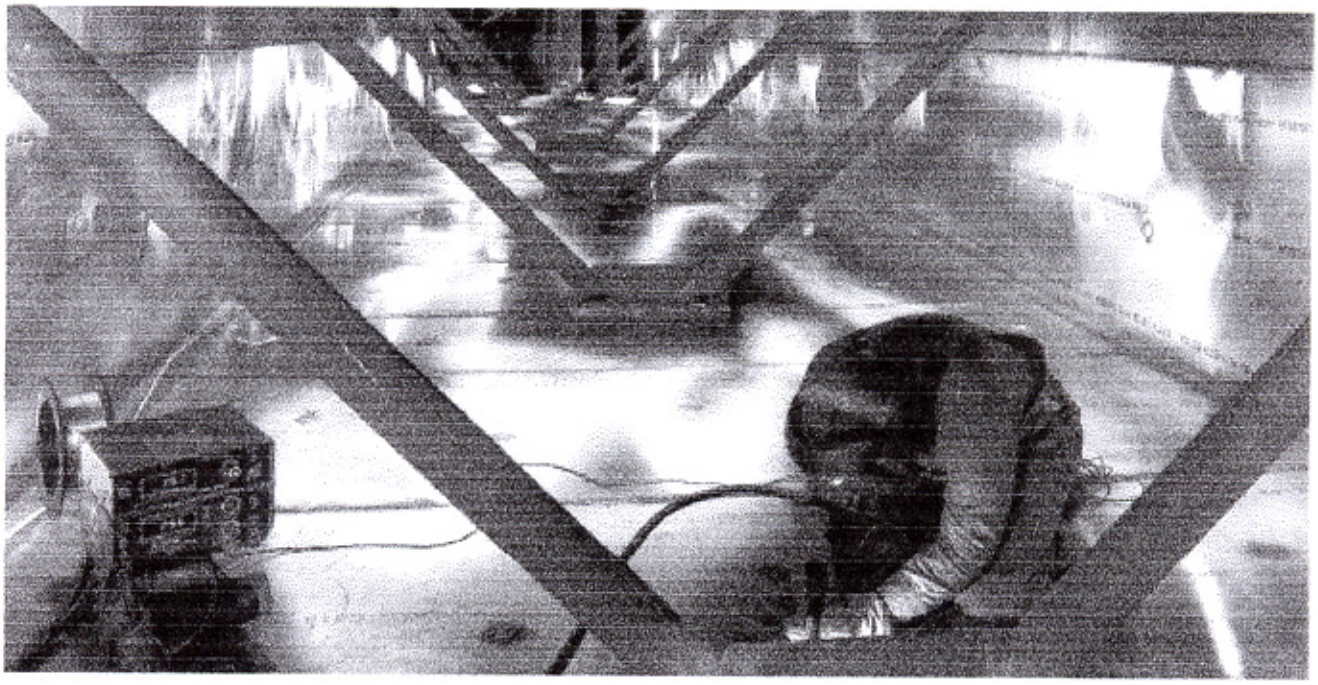
Alloy	20% Acetic	45% Formic	10% Oxalic
304	0.1	48	48
316L	0.1	23	48
317LM	0.24	11	47
904L	0.6	7.7	27
AL-6XN	0.1	4.6	11
E-BRITE	0.1	2.6	2.8

Bulletin 203 contains detailed fabrication information.

RADATA SHEET AL-6XN®

APPLICATIONS & USES

alloy



AL-6XN alloy is one of the most widely used 6% molybdenum stainless steels. This alloy was originally developed to resist chloride pitting and crevice corrosion in hot seawater handling systems. The first major use for the material was for heat exchanger tubing used in seawater power condensers. Its outstanding characteristics have led to its widespread usage in variety of corrosive applications, both with chlorides and without. AL-6XN is now a standard material of construction in the pulp and paper industry, desalination equipment, petrochemical plants, food processing, and pollution control units.

The outstanding characteristics of AL-6XN alloy are:

1. Chloride pitting and crevice corrosion resistance
2. Stress corrosion cracking (SCC) resistance
3. Moderate price
4. High mechanical properties and ASME Code values
5. Availability in all product forms from warehouse stock

Understanding these five characteristics is necessary to fully appreciate the benefits of AL-6XN alloy. In order to help in this understanding each characteristic is explained in greater detail in the following sections of this brochure. Comparisons with some other common stainless steels and nickel alloys are included.

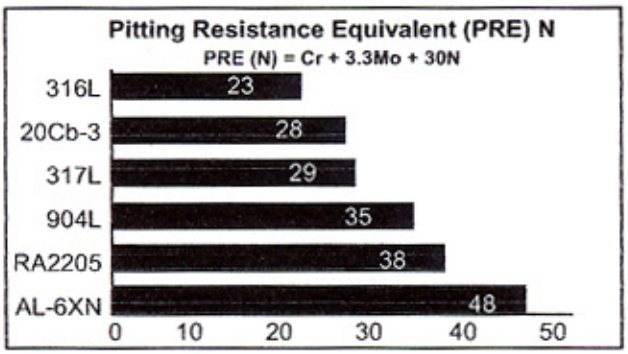
1. CHLORIDE PITTING AND CREVICE CORROSION RESISTANCE

Common 18-8 stainless (304) has good general corrosion resistance. Problems occur when chlorides, normally in the form of salts, are encountered. Instead of corroding in a slow and uniform fashion, the 304 pits. These pits can penetrate through a vessel wall causing leakage, even though the equipment appears to be completely intact. As an example, after WWI the U.S. acquired German patents on 18-8 stainless steel. Based on its corrosion resistance, the U.S. Navy figured that the material was a logical choice for a shipboard piping system. Upon being put into service pitting corrosion quickly turned the piping into a seawater sprinkler system, instead.

Soon after, it was discovered that additions of molybdenum could improve pitting resistance in stainless steels. This resulted in the development of type 316L stainless. 316L stainless is essentially 304L stainless plus 2 to 3 percent molybdenum.

Over the years, alloys containing greater amounts of molybdenum than 316L stainless have been developed. And recently improvements in alloy production have allowed for the addition of nitrogen to stainless steels. It was discovered that nitrogen additions in conjunction with molybdenum were beneficial in resisting pitting.

Various methods have been created to help rank these alloys' relative pitting resistance. One of the more popular methods is the pitting resistance equivalent or PRE(N). The PRE(N) is a value based on a mathematical equation using the three alloying elements most responsible for pitting resistance: molybdenum (Mo), chromium (Cr), and nitrogen (N). The PRE(N) value for several alloys are given in the following chart.



Crevice corrosion is more of a problem than pitting, where chlorides are concerned. A crevice is formed any time something is in contact with the metal. If sludge collects in the bottom of a vessel, crevice corrosion under the sludge may cause a sudden leak. Crevices are also formed under barnacles and other marine life. Tight metal to metal crevices, such as in threaded connections, are the worst scenario. Crevice corrosion under gaskets in flanged connections is a frequent problem. The problem occurs mostly if the process liquid contains enough chlorides to be moderately corrosive. These chlorides will concentrate to very high levels in the crevice area. Additionally, the liquid within the crevice will become acidic. As a result, the bulk of the equipment must only tolerate, for instance 70F neutral salt water, while within the crevice the alloy must resist a concentrated salt solution with traces of HCl.

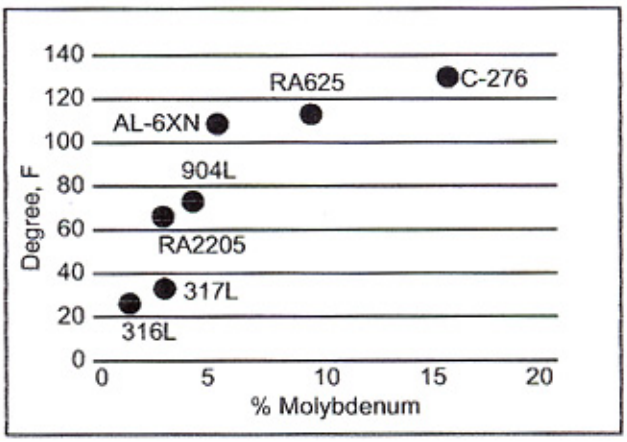
As a rule, the tighter the crevice and the higher the temperatures the more severe the potential is for crevice attack.

The Benefits of Molybdenum

As in pitting, alloying with molybdenum is beneficial. AL-6XN has good crevice corrosion resistance in seawater. 316L has poor resistance. Slightly greater additions of molybdenum such as in RA2205 and 904L are not quite adequate for hot seawater.

Critical crevice corrosion temperatures (CCCT) for alloys with varying additions of molybdenum are listed below. Higher CCCT values generally correlate to greater resistance to crevice corrosion attack.

Effect of Mo Content on CCCT
10%$FeCl_3 \cdot 6H_2O$



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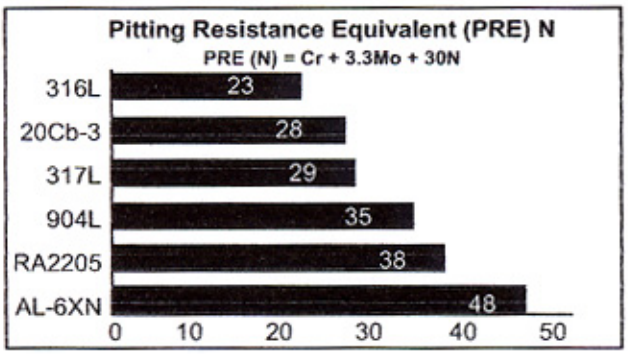

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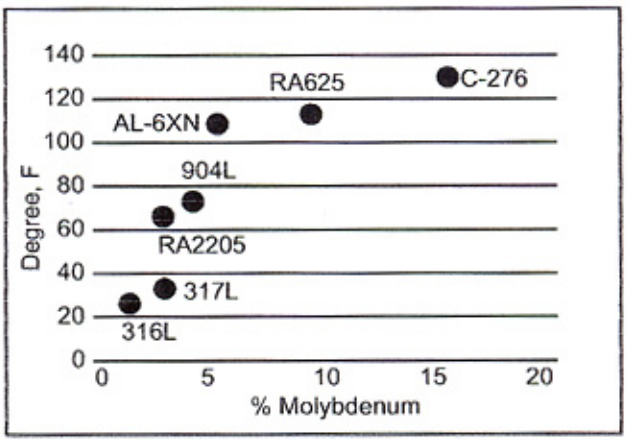

3. MODERATE PRICE

The following table gives relative pricing for various corrosion alloys. 316L = 1.00

Grade	*Ratio, relative to 316L*
316L	1.00
RA2205	1.20
317LMN	1.80
20Cb-3	3.0
Alloy 400	3.4
AL-6XN	3.55
C-276	4.95

All pricing data was based on market conditions for 1/4" plate during January 2000.

4. STRENGTH

High strength permits construction with thinner walls. One of the advantages of alloys containing nitrogen such as AL-6XN and duplex alloys is their greater strength than 316L stainless. As you will note, AL-6XN is rated for stresses over 66% higher than 316L at 200°F. This added strength coupled with AL-6XN's corrosion resistance may allow for lighter weight designs. Making full use of AL-6XN's advantages can help bridge the initial cost differences between AL-6XN and 316L.

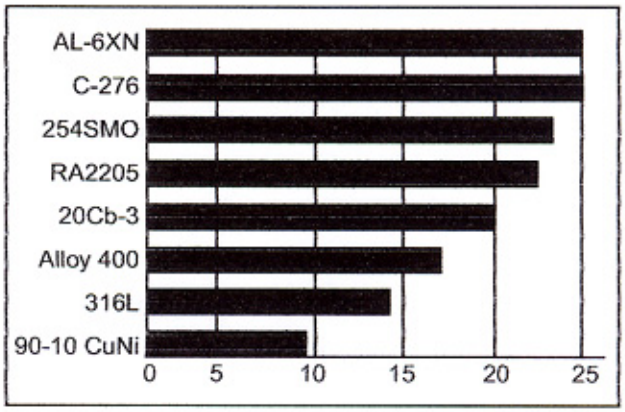

Figure 3 - ASME Boiler & Pressure Vessel Code, Section VIII, Division 1, Allowable Stress Values @ 200°F (ksi).

5. AVAILABILITY

316L	Excellent from stock
317L	Limited from Stock
317LMN	Limited from Stock
RA2205	Sheet, plate, bar, pipe, tubing, fittings from stock
20Cb-3	Very good from stock
AL-6XN	Sheet, plate, bar, pipe, tubing, fittings, forging billets from stock
C-276	Very good from stock

Mechanical Properties (min.)

	Ultimate Tensile (psi)	0.2% Yield	%Elong
Sheet Under 3/16" Thick:	104,000	46,000	30
Plate 3/16" through 3/4"Thick:	100,000	45,000	30
Welded Pipe, Bar, Forgings:	95,000	45,000	30

Chemistry
AL-6XN Alloy (UNS No. N08367)

	Min	Max	Nominal
Cr	20.00	22.00	20.50
Ni	23.50	25.50	24.00
Mo	6.00	7.00	6.20
Fe	Balance		43.00
Mn	—	2.00	0.50
Si	—	1.00	0.40
Cu	—	0.75	0.15
N	0.18	0.25	0.22
C	—	0.03	0.02
P	—	0.040	0.025
S	—	0.030	0.002

Specifications

Product Form	ASTM		ASME
Plate, Sheet & Strip	B 688	A 240	SB-688
Bar & Shapes	B 691	A 479	SB-691
Welded Pipe	B 675	A 312	SB-675
Welded Pipe w/Filler	B 804	A 358	SB-804
Seamless Pipe & Tube	B 690	A 312	SB-690
Welded Tubing	B 676	A 249	SB-676
Forged Pipe Flanges, Fittings	B 462	A 182	
Wrought Welded Fittings	B 366		SB-366
Forgings	B 564		SB-564
Billets & Bars for Reforging	B 472		
Castings (CN-3MN, UNS J94651)	A 743	A 744	

SOME AL-6XN® ALLOY APPLICATIONS

Petroleum Refining

1. U.S. Gulf Coast Refinery

16ga sheet used for top nine trays in main atmospheric crude tower. High sulfur crude being processed. Service life 10-11 years. Previous materials 11ga 410SS and 11ga Alloy 400. Service lives for previous alloys were less than 3 years.

2. Gulf Coast Refinery

Lube extraction unit. 8" dia. pipe and fittings. Heater to warm feed oil to 600°F prior to entering the extraction unit. 316L corroded by n-methyl perolodone in the feed oil.

3. U.S. Gulf Coast Refinery

Fluid Cat Cracker (FCC) Reboiler. AL-6XN replaced steel suffering from excessive sulfide scaling leading to under deposit corrosion. Steel lasted 18 months. Light oil on tube side inlet 550°F outlet 400°F.

4. Midwestern U.S. Refinery

Cumene unit transfer piping. Temperatures between 400-450°F at 450 psi. In the past, pitting was observed in 316L, 825, and Alloy 20 within 6 months time. AL-6XN in service over 3 years with no reported problems.

6. Midwestern U.S. Refinery

AL-6XN used to replace Alloy 400 trays in crude oil distillation unit. AL-6XN used in the top of the tower where crude reflux gas at 100°F mixes with 300°F gas. The environment contained Ammonium chloride (NH_3Cl), ammonium sulfate (NH_3SO_2) and amines

7. Midwestern U.S. Refinery

11 gage AL-6XN sheet used to line a atmospheric crude oil distillation tower. Unit retrofitted to process high sulfur crude. Put into service in 1999.

Power Plants

1. Nuclear Generating Station - Southeastern U.S.

AL-6XN selected to replace 304L piping for the main and auxiliary service water piping systems. 304L piping suffered MIC corrosion. Water supplied from a fresh water man made reservoir. Water testing showed 3 ppm Cl^-, 6 ppm sulfates, 38 ppm total solids, a pH of 5, and a maximum temperature of 95°F.

2. Utility Company - Northeastern U.S. Coast

AL-6XN tubing used to re-tube two feedwater heaters cooled using seawater, which previously utilized 304SS. AL-6XN chosen for its greater corrosion resistance and mechanical properties. Study estimated that AL-6XN condensers though initially $50,000 higher in initial cost would create over $350,000 in savings over the life of the condenser through decreased tube failure, lower maintenance requirements, and fuel cost savings.

3. Western U.S. Co-generation Plant

18 gage wall tubes of 90-10 Cu-Ni in a steam turbine condenser replaced using 22 gage wall AL-6XN tubing. Original tubes suffered deep pitting and erosion attack at the inlet areas. Fresh water is used for cooling in the closed loop system. Flow was 8 ft/sec. Water analysis showed high levels of chlorides, sodium and sulfate ions along with high levels of calcium and magnesium. Scaling of the water led to crevice corrosion under the deposits.

Food and Beverage

1. Western U.S. Brewery

Hot water line piping supplying preheated water for the brewing process. Previous alloy, 304SS, suffered chloride SCC in heat affected zone (HAZ) and in pipe elbows. AL-6XN has been in service with no problems after 6 years.

2. Midwestern U.S. Brewery

Thin walled piping in hot water line supplying preheated water for the brewing process. Previous alloy, 304SS, suffered chloride SCC.

3. Corn Refiner

Replaced 316L in corn sweetener process fructose line, which was suffering chloride SCC. 316L lasted less than 2 years. Temperature -200°F.

4. Midwestern U.S. Cereal Company

AL-6XN replaced 316L stainless in a rotating closed-barrel type cooker design. 316L suffered chloride SCC and crevice corrosion due to salt added to the cereal batter. AL-6XN used for mixer paddles and cooker unit. After 18 months, of service no problems were reported in the new AL-6XN cookers.

5. Meat Processing Plant
AL-6XN used in meat cooker to replace 316L components suffering chloride SCC due to the combination of temperatures above 140°F and chlorides in the meat being cooked.

6. Baby Food Manufacturer
Tanks suffering pitting attack from cleaning procedure utilizing a wash with 10% tricalcium phosphate followed by a chlorine sanitizing treatment. 10 ga. AL-6XN selected to replace the 304.

7. Salt Production
AL-6XN used for screw type conveyors at several plants. Conveyors transport hot salt after the drying stage. Replaced several alloys. 316L had chloride SCC and sometimes pitting at the flight to shaft joint. AL-6XN chosen for its greater resistance to chlorides. Replaced alloy 400. This based on improved abrasion resistance.

Air Pollution Control Equipment

1. Eastern U.S. Chemical Plant
Scrubber and electrostatic precipitator of three incinerators at a large chemical complex. Incinerators treat liquid and solid wastes from both chemical production and common refuse from the plant. AL-6XN chosen for its resistance to both chloride and acid attack.

2. East Coast Pharmaceutical Plant
Ductwork off of a Calvert Scrubber treating exhaust gases from a pyrolyzer. Organic and pharmaceutical waste products being processed contain sulfur and chlorides.

3. Utility Company - Korea
10 Flue Gas Desulfurization (FGD) Scrubber Units used AL-6XN for main absorber bodies, internals, piping systems, and structural members. Over $US 20 million of AL-6XN utilized for its resistance to the combined HCl, sulfuric acid (H_2SO_4)and chlorides in the environment.

4. Midwestern U.S. Utility
Downcomer duct lining. AL-6XN used for two 13 foot diameter ducts to replace 317LM which suffered severe pitting corrosion. After 3 years service AL-6XN still in excellent condition.

5. Midwestern U.S. Utility
Wallpapering using AL-6XN as lining on carbon steel duct carrying flue gases to the exhaust stack. Steel was suffering pitting attack due to condensation of acids and chlorides onto the side walls and floor for the ducting. Lining was a temporary fix and the duct was taken out of service after the needed 5 years with no problems in the AL-6XN liner.

6. Medical Waste Incinerator - Mexico
Spray nozzles and quench area of ducting coming off of a medical waste incinerator. 316L, the original alloy, pitted due to chlorides present from the incineration of plastics.

Mining

1. Coal Mine - Poland
Brine concentrators to treat drainage and wastewater from the mine. Water is highly brackish nearing the chloride content of seawater. Brine slurry reaches 26% dissolved sodium chloride (NaCl), 8-10% Dissolved magnesium chloride ($MgCl_2$), 30% suspended NaCl, pH 6-8, and a temperature of 230°F.

2. Mining Operation
Pollution control unit off of a fluidized bed ore roaster unit at a U.S. gold mining operation. AL-6XN utilized for resistance to corrosion by mixture of chlorides, sulfuric acid, and hydrochloric acid.

Chemical Plants

1. Southern U.S. Pulp & Paper Mill
Tall oil distillation column installed in October 1989. 14 feet in diameter and 160 feet tall. AL-6XN used for the column, heat exchangers, packing, reboiler, piping, vapor lines, and pumps. AL-6XN showed no visible corrosion after 10 years in service.

2. Midwestern U.S. Chemical Plant
Two Fatty Acid distillation towers. AL-6XN installed in 1996. AL-6XN was used for the bottom half of the tower and 317L used for the top. Pitting occurred in the bottom in 317L and 316L used previously in under 18 months time. Pitting due to the formation of ammonium chloride in the process. Temperatures in the 500°F range and there were contaminants by sulfur compounds and chlorides. No pitting reported after 18 months in service. AL-6XN was also used in some piping systems, packing, and a heat exchanger. After 4 years of service no problems observed.

3. Midwestern U.S. Chemical Plant

AL-6XN used to replace 316L material for holding tanks. Tanks contain ingredients for the manufacture of hair spray and anti-perspirants, which included chlorinated compounds. 316L suffered both general and pitting type corrosion. Process temperatures varied to a maximum of 185°F.

Seawater and Marine Environments

1. Biosphere II - Arizona

60,000 square feet of AL-6XN sheet used for the artificial ocean floor due to its high level of resistance to pitting and crevice corrosion in seawater. Temperatures were ambient. Design life is 100 years.

2. Electrical Transmission Equipment

Electrical transformers for coastal areas. Epoxy coated carbon steel corroded. 304L used as next replacement material and suffered chloride SCC. AL-6XN picked for its resistance to SCC and pitting corrosion in chloride bearing environments.

3. Desalination - Bahamas

Fittings in desalinization unit. Seawater neutral pH, 80-90°F. AL-6XN fittings made from bar stock replaced cast CK-3MCuN, which suffered pitting/crevice attack.

AL-6XN made into coiled tubing for flow lines in the North Sea. 2600 feet of tubing utilized. Conditions reported to include 4.9% H_2S, 15%CO_2, High Chlorides, 230°F.