Technical Data Sheet

AL 29-4C®

Stainless Steel: Superferritic

(UNS S44735)

INTRODUCTION

AL 29-4C® alloy, is a superferritic stainless steel developed by ATI in the early 1980s specifically for power plant surface condenser tubing. Since that time over 60 million feet of superferritic condenser tube has been put into service. The alloy has excellent resistance to brackish, polluted or high chloride waters, e.g., seawater. AL 29-4C alloy has also outstanding potential for use in tubing for desalination equipment and has seen extensive use in high efficiency furnace equipment. While maintaining all attributes of conventional ferritic stainless steels, AL 29-4C alloy provides the following advantages over other competitive materials:

1. High resistance to severe chloride environments, such as seawater
2. Better resistance to vibration damage than titanium
3. Better resistance to erosion-corrosion than titanium and copper base alloys
4. Better heat transfer properties than austenitic stainless steels
5. Low cobalt content
6. Cost effectiveness.

Tubes produced from properly manufactured AL 29-4C material should be capable of passing the ASTM G48 Practice C pitting test when tested at 70°C for 72 hours with the sample in the as-produced condition.

Alloy Development

Historically, the major disadvantage in using conventional stainless steels in seawater and other aggressive waters has been the susceptibility of these steels to chloride pitting and crevice corrosion. Conventional stainless steels are particularly susceptible to corrosion if deposits form or low flow conditions exist in high chloride waters.

The $FeCl_3$ test was conducted in a manner similar to ASTM procedure G48B and used teflon blocks held with rubber bands to create crevice conditions. Streicher's results are shown schematically in Figure 1.

The effect of chromium and molybdenum is synergistic, i.e., less molybdenum is needed at higher chromium levels. For example, alloys have 26% chromium and 3% molybdenum exhibited pitting or crevice attack in the two corrosion tests while alloys containing 27-30% chromium and 3.5-4% molybdenum were resistant in both tests. High levels of molybdenum (e.g., 5%) were found to decrease both ductility and stress corrosion cracking resistance (in 42% boiling magnesium chloride). These limits have come to define the family of superferritic stainless steels S44735 and S44660 known as AL 29-4C and SEA-CURE® alloys, respectively.

The only other deliberate alloying additions to AL 29-4C alloy are titanium and niobium as stabilizing elements. The stabilizers are added to combine with carbon and nitrogen to improve weldability, toughness and resistance to integranular corrosion.

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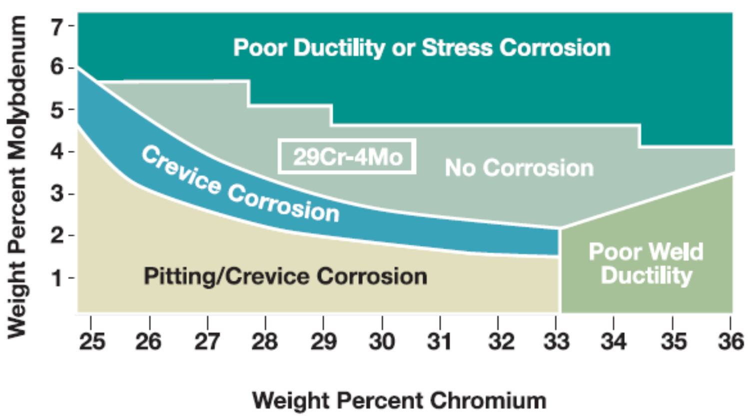
Figure 1 — Effect of Chromium and Molybdenum on the Properties of Fe-Cr-Mo Alloys.



TYPICAL COMPOSITION

Table 1

Element	Weight Percent
Chromium	29
Molybdenum	4
Nickel	0.3
Manganese	0.5
Phosphorus	0.03
Sulfur	0.01
Silicon	0.4
Cobalt	0.03
Carbon	0.02
Nitrogen	0.02
Titanium & Niobium	0.5

CORROSION RESISTANCE

Pitting & Crevice Corrosion Resistance The most important corrosion property to consider when evaluating stainless steels for service in aggressive waters is resistance to chloride crevice corrosion. AL 29-4C alloy is extremely resistant to chloride crevice corrosion, after welding, annealing and post weld cleaning of oxide discoloration. This is typically done by acid pickling for the highest level of corrosion resistance to warm seawater. However, bright annealed tubing has demonstrated acceptable performance in less severe environments.

Figure 2 compares the performance of AL 29-4C alloy with the conventional Type 316L stainless steel in the ferric chloride test at room temperature for different test times. Resistance to corrosion in this laboratory test is often correlated with resistance in low temperature seawater. AL 29-4C alloy shows no crevice or pitting corrosion while Type 316L is severely attacked.

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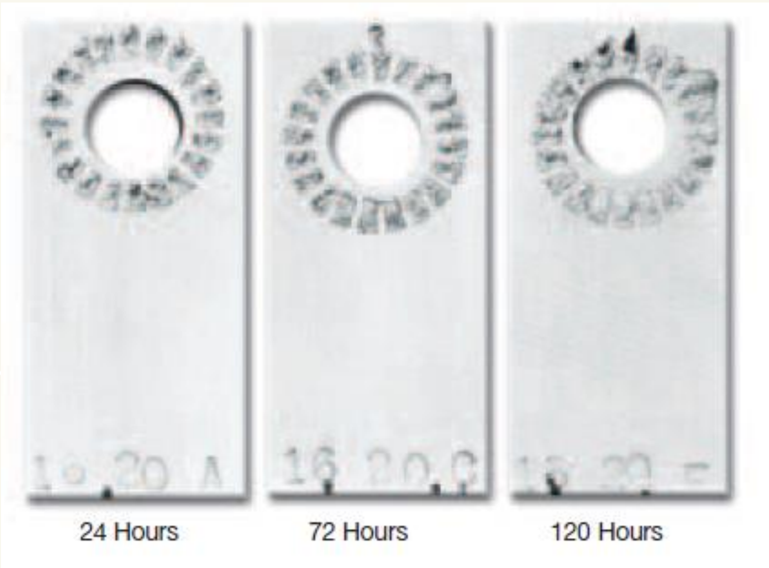
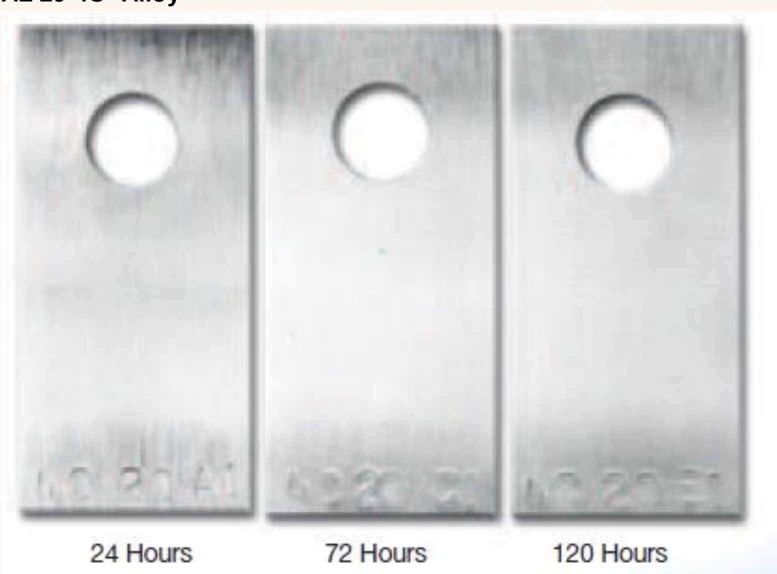
Figure 2 — Crevice Corrosion Test in 10% Ferric Chloride at 70°F (21°C).

Type 316L



AL 29-4C® Alloy



The severity of the ferric chloride test can be increased by increasing the test temperature or acidifying the solution. Figure 3 compares the typical performance of AL 29-4C tubing to that of titanium tubing (Grade 2) at room temperature, 95°F (35°C) and 122°F (50°C). The excellent resistance of ATI 29-4C tubing is evident.

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Figure 3 — Crevice Corrosion Test in Ferric Chloride for 72 Hours.

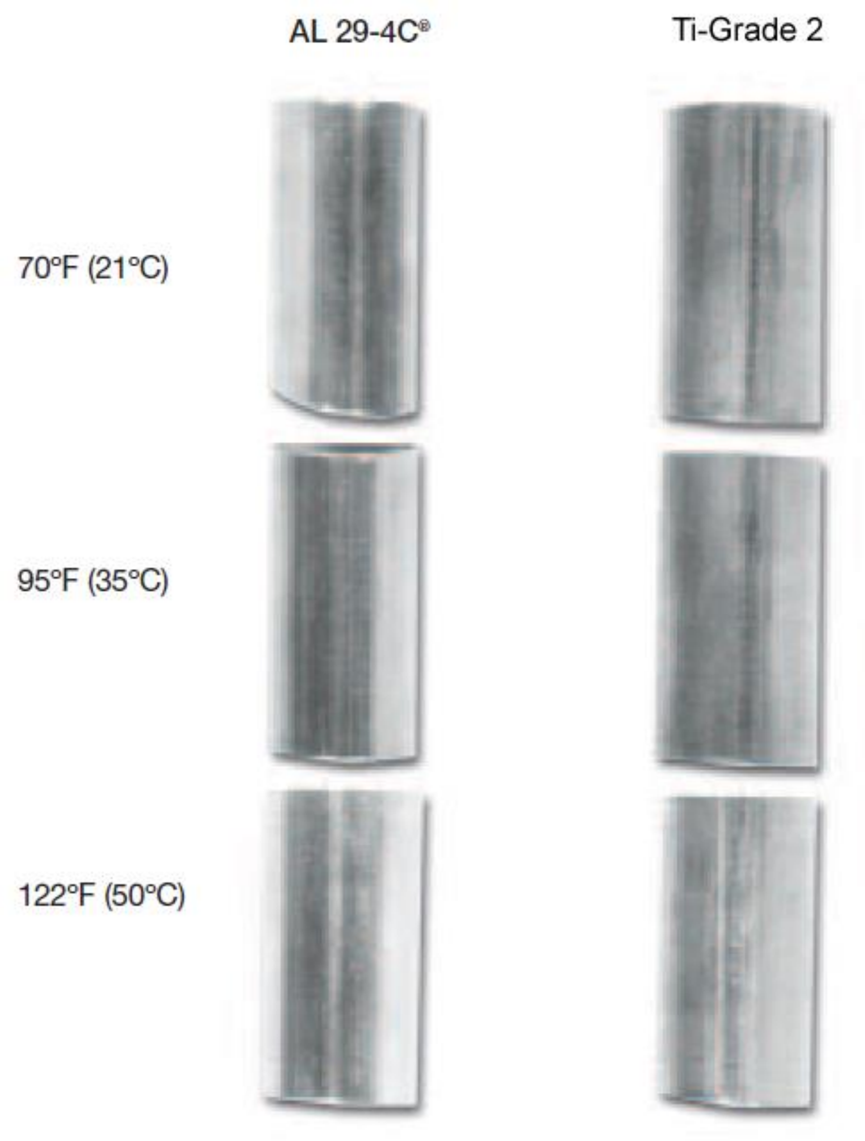

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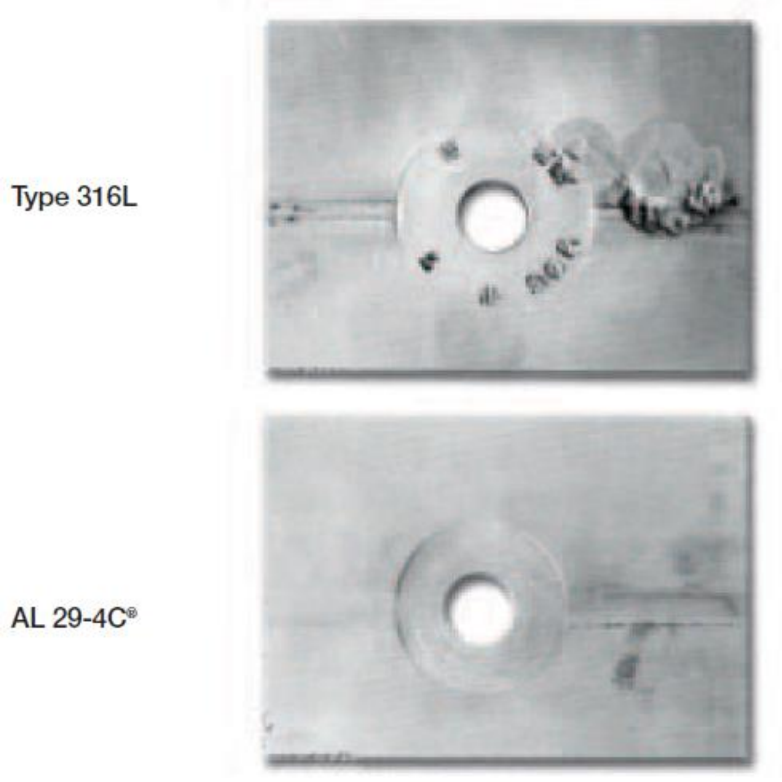
Figure 4 — Test Panels with Artificial Crevices after 9 Months of Exposure to Seawater.



Seawater Testing

AL 29-4C alloy has also been tested in a seawater immersion test. The test was conducted in quiescent seawater for a 9-month period. The average water conditions were: 53°F (11.6°C), 30,900 ppm salinity, pH 7.8 and dissolved oxygen 8.6 ppm. Figure 4 compares the performance of Type 316L, with AL 29-4C alloy after nine months of immersion. Artificial crevices were imposed prior to immersion on welded annealed and pickled samples. The AL 29-4C samples showed no evidence of corrosion; however the Type 316L suffered crevice corrosion. The seawater immersion results clearly show the superior performance of AL 29-4C alloy.

General Corrosion Resistance

AL 29-4C alloy like other superferritic stainless steels, offers excellent resistance to a broad range of corrosive environments. Laboratory tests have demonstrated that the AL 29-4C alloy is extremely resistant in some brine environments (Table 2). AL 29-4C alloy performed better than Type 316L stainless steel, titanium and nickel-copper alloy 400.

Table 2 — Corrosion Tests in Brines*

Environment	Alloy	Observed Corrosion
Boiling Saturated NaCl + 10% Na_2CO_3 pH 11 (230ºF)	AL 29-4C®	No Attack
	Ti-Grade 2	No Attack
	Alloy 400	Crevice Attack
Boiling 25% NaCl + 0.38% Na_2SO_4 + 0.15% CaCl pH 6.7-7.2 (226ºF)	AL 29-4C	No Attack
	Ti-Grade 2	Crevice Attack
	Alloy 400	Crevice Attack
	T-316L	Crevice Attack

*72 hour test **based on** ASTM G48

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Table 3 — Corrosion Results for AL 29-4C® Alloy

Environment	Temperature ºF (°C)	Corrosion Rate MPY (mm/year)
20% NaOH	250 (121)	0.6 (0.015)
40% NaOH	250 (121)	0.1 (0.003)
60% NaOH	250 (121)	0.3 (0.008)
60% NaOH	315 (157)	1.6 (0.041)
70% NaOH	250 (121)	0.2 (0.005)
70% NaOH	350 (177)	1.9 (0.048)
10% HNO_3	300 (149)	0.1 (0.003)
20% HNO_3	300 (149)	2.2 (0.056)
30% HNO_3	300 (149)	4.1 (0.104)

Stress Corrosion Cracking

The ferritic structure and the low level of copper and nickel make AL 29-4C alloy highly resistant to chloride stress corrosion cracking. Laboratory tests of annealed strip have shown no evidence of stress corrosion cracking in U-bent samples after 500 hours in boiling 26% sodium chloride.

Intergranular Corrosion Resistance

AL 29-4C alloy contains a deliberate titanium and niobium addition to stabilize the carbon and nitrogen. AL 29-4C alloy is resistant to intergranular corrosion as determined by the copper-copper sulfate-sulfuric acid tests detailed in ASTM Specification A 763, Practice Y.

PHYSICAL PROPERTIES

Typical mechanical and physical properties of AL 29-4C alloy, titanium (Grade 2), and 90-10 copper-nickel are compared in Table 4. AL 29-4C alloy has considerably higher yield strength, tensile strength and modulus of elasticity than either titanium or 90-10 copper-nickel. Condenser tube mechanical properties are of most interest when considering tube-to-tubesheet joints. The most common tube-to-tubesheet joint is roller expanded.

AL 29-4C tubes can be rolled and flared or belled into a variety of tubesheet materials if proper tools are used. Expansion can be successfully accomplished using 3 to 5 roller expanders, and selection of the number of rolls is largely a matter of personal preference. Figure 5 shows several examples of AL 29-4C alloy demonstrating the ductility of the tubular product. Amount of expansion, achievable pullout strength and other important parameters depend to a large extent on the specific tubesheet involved. A typical tube sheet material used in conjunction with AL 29-4C tubes is AL-6XN® (UNS N08367) plate.

If clad plate is utilized for tube sheet material, the tube-to tubesheet joints are typically seal welded with a filler metal suitable for the corrosive service.

The high modulus of elasticity of AL 29-4C alloy results in superior resistance to vibration. This may permit much greater support sheet spacings for the same resistance to vibration as titanium, or may allow for considerably thinner tube walls.

Of more significance, perhaps, is the fact that if a condenser was designed for a higher modulus alloy such as 70-30 copper-nickel, or a heavier wall, low modulus alloy, then titanium often cannot be used in practical wall thicknesses because the modulus is too low to provide sufficient stiffness. AL 29-4C alloy is an excellent material for these applications.

The thermal conductivity coefficient (k) of the stainless steels is considerably lower than the coefficient for the copper, brass or cupro-nickel alloys. Experience has shown that this resistance to heat transfer is only a few percent of the total resistance. Figure 6 demonstrates the effects of corrosion and fouling on condenser tube as a result of service exposure. Similar results in many applications have made the stainless steels viable heat transfer materials. The thermal conductivity coefficient of AL 29-4C alloy is better than conventional austenitic stainless steels.

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Figure 4 — Comparative Mechanical and Physical Properties of Condenser Tube Materials

Property	AL 29-4C®	Ti-Grade 2	90-10
Yield Strength ksi (MPa)*	80 (552)	50 (345)	50 (345)
Ultimate Strength ksi (MPa)	95 (655)	70 (483)	60 (414)
Elongation (percent)*	20	20	25
Elastic Modulus 10^6 psi (GPa)	30 (207)	15 (103)	18 (124)
Thermal Conductivity BTU/hr/ft^2/in/ºF (W/m•K)	119 (17.2)	114 (16.5)	312 (45)
Thermal Expansion in/in/ºFx10^6 -- 32ºF-212ºF (x10^{-6}/°C - 0ºC-100ºC)	5.2 (9.3)	4.8 (8.6)	8.8 (15.8)
Density lbs/in^3 (g/cm^3)	0.277 (7.67)	0.163 (4.51)	0.323 (8.94)

* Typical properties for condenser tubing.

Figure 5 — AL 29-4C® Tube Tests

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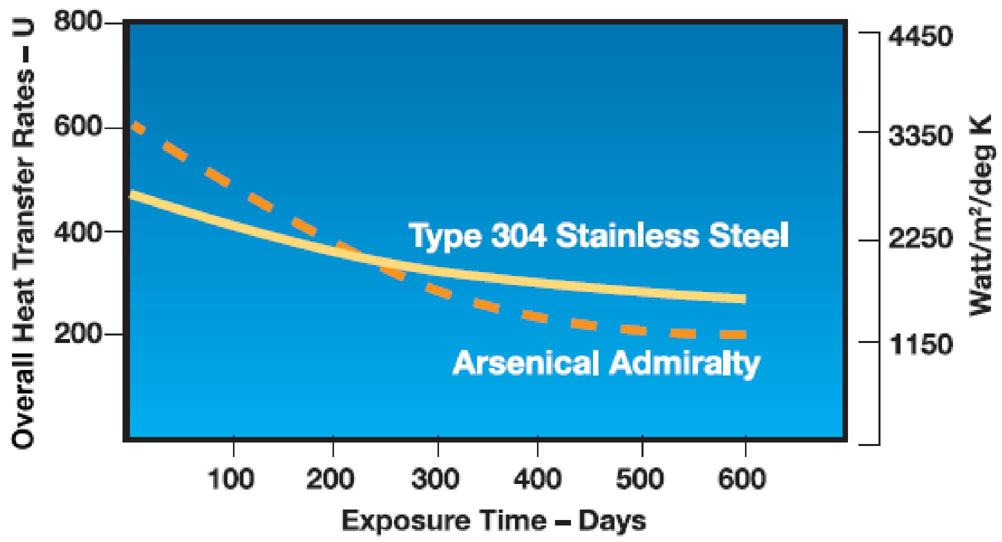
Figure 6 — Overall Heat Transfer vs. Exposure Time



Availability

AL 29-4C welded tubing is available in thicknesses 0.010 inches (0.254mm) to 0.050 inches (1.27mm). Other sizes may be available on request. AL 29-4C flat-rolled products are available in thicknesses up to 0.050 inches (1.27 mm) and standard widths up to 36 inches (914mm).

SPECIFICATIONS & CERTIFICATES

ASTM A268, A240
ASME SA-268, SA-240

QUALITY

The severe ASTM G48 Practice C Pitting Test conducted at a temperature of 70°C for 72 hours readily separates good-quality from poor-quality AL 29-4C material. Both proper annealing and oxide scale prevention or removal are critical parts of proper tube making and have a major influence on the ability of AL 29-4C tubular products to exhibit their maximum potential for corrosion-resisting performance.

Figure 7 shows the failures that can occur with properly descaled material that has been annealed at the wrong temperature. Figure 8 shows the unaffected appearance of a tube that was produced properly and passed this severe corrosion test.

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Figure 7 – Macrographs after corrosion testing of AL 29-4C® tubes that were produced improperly. (Sample Length = 2 inches)

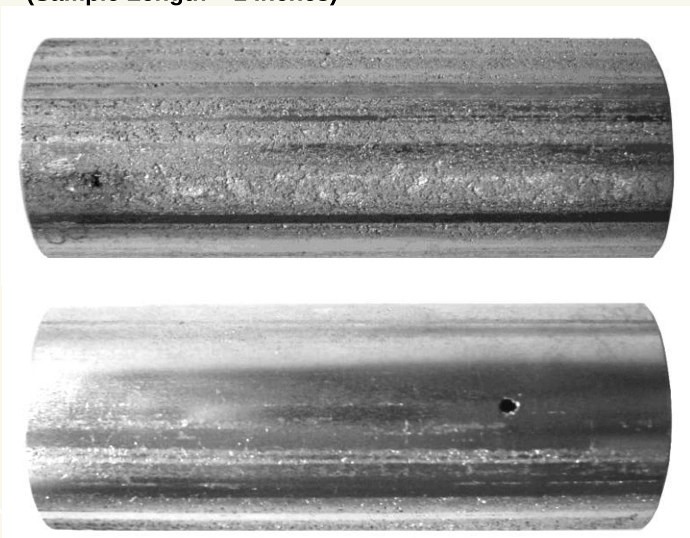

Figure 8 – Macrograph after corrosion testing of an AL 29-4C® tube that was produced properly. (Sample Length = 2 inches)

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