

Stainless Steel AL 29-4C[®] Alloy Heating and Ventilating Reference Data (UNS Designation S44735)

TYPICAL COMPOSITION

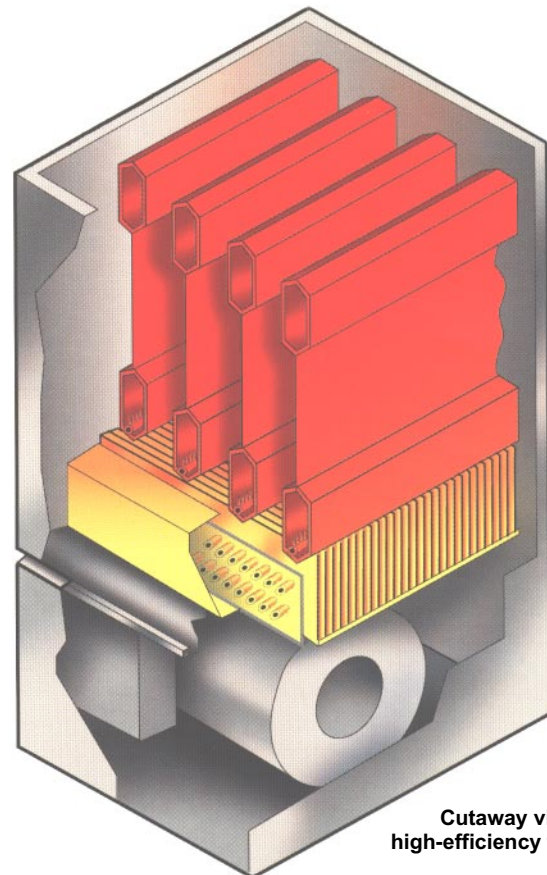
Element	Wt. Percent
Carbon	0.02
Manganese	0.50
Phosphorus	0.03
Sulfur	<0.01
Silicon	0.35
Chromium	29
Nickel	0.30
Molybdenum	4
Nitrogen	0.02
Titanium+Columbium (Niobium)	0.6
Iron	Balance

PRODUCT FORMS AVAILABLE

Strip and Sheet:	Widths up to 36" (91.4 cm) Thickness to 0.050" (1.27 mm)
Vent Pipe:	Sizes available on application
Flexible Hose:	Sizes available on application

GENERAL PROPERTIES

AL 29-4C[®] alloy is a superferritic stainless steel designed by Allegheny Ludlum for extreme resistance to chloride ion pitting, crevice corrosion and stress corrosion cracking (SCC), as well as general corrosion in oxidizing and moderately reducing environments. The alloy was developed in the early 1980s for welded condenser tubing to be used in seawater and brackish water by the power generation industry. It is this extreme resistance to pitting and crevice corrosion that has led to the installation of over 2000 miles of AL 29-4C tubing in power plant condensers and heat exchangers.



Cutaway view of a high-efficiency furnace

The superferritic stainless steel AL 29-4C alloy shows excellent resistance to chloride ion pitting, crevice corrosion and stress corrosion cracking (SCC). This resistance makes it an ideal choice for battling the corrosive condensate of partially and fully condensing

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natural gas and propane burning appliances (except for high sulfur fuel sources). Its low alloy content, compared to other high-performance alloys, makes it an economical choice as well.

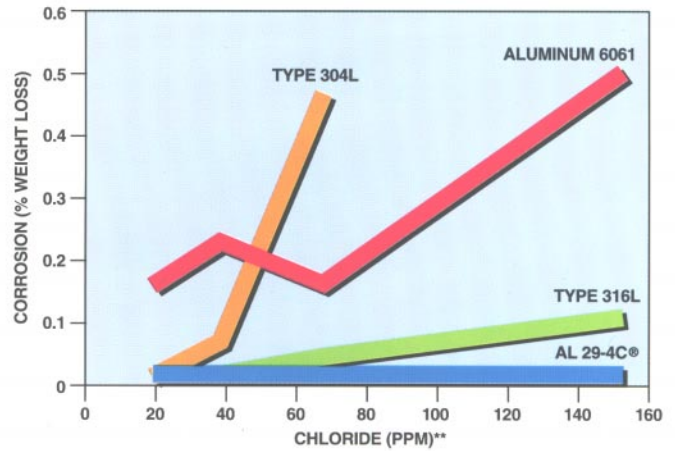
The Condensate Problem

High efficiency in gas heating appliances is achieved when heat from the flue gas is extracted before venting it to the atmosphere. Although natural gas (the fuel used for most of the currently available high efficiency home heating appliances) is relatively clean burning, the products of combustion typically include nitrogen oxides, sulfur oxides and hydrogen chloride, as well as the expected water vapor and carbon dioxide. The hydrogen chloride comes from the combustion of chlorides (salt dust), chlorinated solvents, chlorofluorocarbons, and hypochlorite (bleach) vapors entrained in the combustion air supply. Efforts to reduce chloride sources by switching from indoor to outdoor air supplies have not been totally effective due to airborne salt dust (oceans, deserts, industry, road salt, etc.) as well as household laundry vented emanations and pollution emissions.

Nitrogen oxides are a typical by-product of combustion air. Sulfur is present at very low concentrations as odorant compounds added to natural gas. Condensation of these products of combustion yields an acidic solution which contains concentrations of nitric, nitrous, sulfuric, sulfurous and hydrochloric acids. Hydrogen fluoride is also encountered occasionally. This condensate can create either a predominantly oxidizing or reducing environment. Flue gas condensate becomes increasingly corrosive after it is concentrated by repeated condensing and evaporation, such as on heat exchanger surfaces or in vent pipe systems. This environment is often extremely corrosive to ordinary stainless steels (304, 316, 430, 439, 444) and aluminum as displayed in Figure 1.

Additionally, condensate in conjunction with cyclic thermal stresses and vibratory stresses from normal operation of a heating appliance have caused high temperature plastics to crack and plastic vent pipe joints to fail, prompting consumer advisories.

Figure 1. Gas-fired furnace flue gas corrosion results*



*Heat Exchanger Simulator corrosion tests performed by Battelle Columbus for Brookhaven National Laboratory under contract to U.S. Department of Energy. Reported in DOE Energy Conservation report titled "Condensing Exchanger systems for Residential/Commercial Furnaces and Boilers, Phase IV"; dated Oct. 1985.

**Chloride level measured in condensate developed in the five test zones.

The Condensate Solution

Since 1983, furnace and vent manufacturers have specified AL 29-4C alloy for gas heating appliance parts where condensing occurs. High temperature concerns coupled with corrosive condensate make AL 29-4C alloy the ideal choice. The Canadian Gas Research Institute found that "Test results have shown AL 29-4C and AL-6XN® (a super corrosion resistant austenitic stainless steel) alloys were the most corrosion resistant alloys of twenty candidate stainless steels evaluated for resistance to chloride-induced corrosion in condensing and partially condensing gas-fired appliances." Field studies have also concluded that the only material with a prolonged history of safe, reliable performance is AL 29-4C alloy.

Since AL 29-4C alloy is a ferritic stainless steel, it does not contain costly nickel like the super austenitic grades, thus making it the right economic choice.

AL 29-4C® Heat Exchangers for High Efficiency Gas Furnaces

In high efficiency furnace designs (typically 90% or greater efficiency), the flue gas is cooled to below the dew point within the furnace in order to recover the latent heat of vaporization of the water vapor. This is typically accomplished in a secondary heat exchanger

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downstream of the combustion chamber and primary heat exchanger. These secondary exchangers commonly employ AL 29-4C tubing, tube sheets, headers, dome covers, turbulators, heat exchanger panels and other components which can come in contact with condensate. By using AL 29-4C heat exchangers, furnace manufacturers have benefited by being able to offer extended warranties in an aggressively competitive market.

AL 29-4C® Alloy for Hot Water Heating

AL 29-4C alloy has been employed for commercial and residential hot water heat systems, in heat exchangers that perform a similar function to that in high efficiency furnaces. For components heavier than 18 gage, AL-6XN alloy has been used in conjunction with lighter gage AL 29-4C alloy.

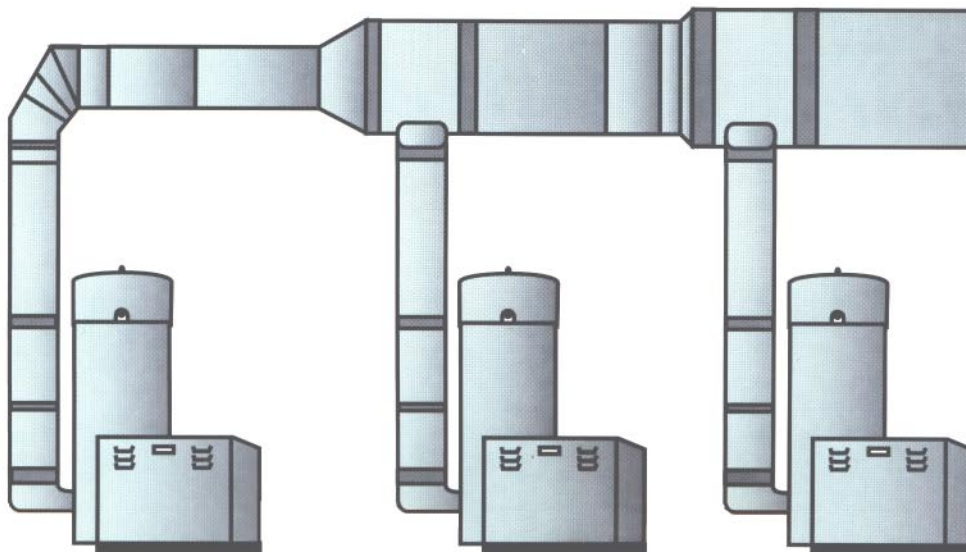
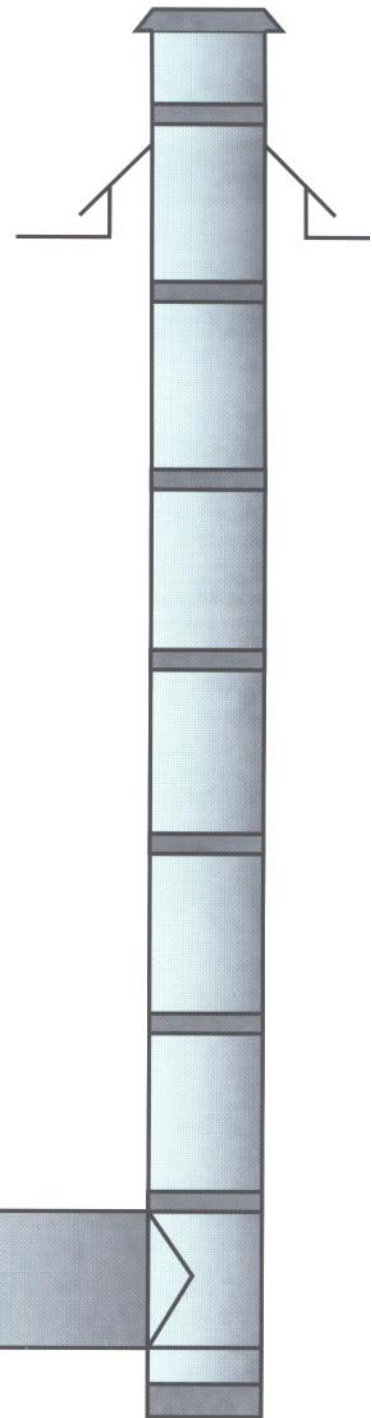
AL 29-4C® Vent Pipe

In mid-efficiency gas furnace designs and some hydronic systems (typically 80% efficiency), the flue gas is not cooled to the dew points, but heat losses can cause condensation to occur in the vent system. In addition to this corrosion concern, the vent system design must accommodate the thermal cyclic stresses in an environment that typically ranges from ambient temperature to 150°C (300°F) and back. AL 29-4C vent systems have the low thermal expansion properties inherent with stainless steels, where high temperature plastic pipes have high expansion coefficients that exert high stress radially and at joints. Also, thinner walls and better thermal conductivity of AL 29-4C alloy versus plastics causes faster heat up which reduces the potential for continuously wet sections of vent, thereby reducing acid levels in the vent.

AL 29-4C alloy vent systems are UL, ULC and cUL listed in flexible and rigid wall for venting Category II, III and IV gas burning appliances side wall or through a chimney.

Contact an AL 29-4C vent pipe manufacturer or Allegheny Ludlum Corporation to inquire about your particular needs.

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FABRICATION PROPERTIES

Forming

The ferritic AL 29-4C alloy possesses the formability characteristic of the ferritic stainless steel alloys as a class, specifically, the alloy has limited stretch formability and excellent drawability.

A draw lubricant with good film strength greatly enhances the tool life and the final part. Parts should be cleaned after forming. Also, tool coatings such as titanium nitride have been helpful in extending tool life. Contact your lubricant supplier and die manufacturer for specifics on your job.

As an example of the forming characteristics of the alloy, strip products have been formed into a variety of tower packing designs, pin drawn shells, drawn header boxes, extruded tube sheets and clam shell heat exchanger panels.

Welding

When using ferritic filler materials such as the preferred commercially available AL 29-4-2® weld wire, the AL 29-4C alloy must only be welded with inert gas shielding techniques such as gas tungsten arc or gas metal arc processes. The use of high nickel fillers will produce lower ductility than stabilized austenitic stainless steels. For weld procedures such as seal welding of tubes to tube sheets, use of stabilized austenitic electrodes and procedures such as shielded metal arc procedures may be considered.

Welding this alloy even with adequate gas protection will usually cause some heat tint or oxidation which should be removed to insure maximum corrosion resistance. Although AL 29-4C alloy resists sensitization through carbon stabilization, as welded conditions result in small reductions in crevice corrosion resistance as shown in Table I below.

Table I

Corrosion Properties of AL 29-4C® welds (G.T.A.W.)	
Condition	(CCCT) ¹
Mill Annealed	129°F (54°C)
As-Welded	125°F (52°C)

¹Critical Crevice Corrosion Temperature (CCCT) based on ASTM G-48B (6% FeCl₃ for 72 hours with crevices).

Seal Welding

The AL 29-4C alloy tubing is most often used with rolled joints, however, the alloy has been seal welded to materials like Type 316 and AL-6XN® alloy. The seal welds to highly alloyed austenitic materials are less ductile than welds made using all ferritic combinations.

Tube Bending

Care should be taken in attempting to bend AL 29-4C tubing. The material is like other ferritic stainless steels in showing relatively low work hardening. Tight bend radii may exceed the uniform elongation capabilities of the material resulting in failure by tensile necking. An approximate 2D bend radius minimum should be considered for the AL 29-4C alloy.

Because the alloy is very resistant to chloride stress-cracking, as shown by prior data, the bends do not require a stress-relief operation after bending. Improper heat treatment in an attempt to stress relieve bends can damage ductility and corrosion properties.

Roller Expansion and Flaring

AL 29-4C tubing can be roller expanded into tube sheets and headers using equipment and procedures used for other tube materials. Tubes can be flared modestly after rolling. The outside diameter of the finished flare should be kept within the elongation limits of the material to prevent flare splits. This is a consideration because ferritic stainless steels exhibit lower work hardening and are less stretch formable than familiar austenitic alloys.

Impact Resistance

AL 29-4C alloy, like other ferritic stainless steels, undergoes a transition from ductile to brittle behavior as the impact test temperature is lowered. The specific temperature at which this transition occurs depends upon section thickness and prior thermal history. Fast cooling from heat treatments above 1000°F (538°C) and thinner sections favor relatively lower impact transitions. This behavior is typical of ferritic stainless steels. To preserve the impact resistance of the mill supplied condition, the maximum use temperature should be restricted to 600°F (316°C).

Corrosion Properties

Important design decisions are often based on corrosion data obtained from accelerated laboratory and field tests. Predicting actual performance in service from such tests requires an understanding of both the metallurgical and the environmental factors that may affect an alloy. The factors that induce corrosion in a real process must be identified and then controlled in an accelerated test for it to be a reliable indicator of actual performance.

The most frequent mode of failure for stainless alloys is localized corrosion induced by chlorides; specifically, pitting, crevice corrosion and stress-corrosion cracking. Austenitic stainless alloys can also corrode by general or intergranular modes of attack in acids and alkalis that do not contain chlorides or other halides. Data from several laboratory and field tests are presented to cover a wide range of possible process solutions.

Extensive testing was conducted in various concentrations of acetic acid at atmospheric boiling temperatures (Table II).

Tests were also conducted in dilute nitric acid in accordance with ASTM A262, Practice C at atmospheric boiling with results as listed in Table III.

ASTM has standardized testing of alloys in ferric chloride solutions as a measure of pitting (G-48A) and crevice (G-48B) corrosion resistance. The critical temperature (maximum temperature for no attack) is a recognized relative measure of the localized corrosion resistance of an alloy in chloride environments. Such data for several alloys are shown in Table IV.

Table II

Acetic Acid Solution	Corrosion Rates Mils Per Year (mm/a)		
	AL 29-4C®	Type 316	Type 304
66% Acetic Acid +100 ppm Cl- as Hc	0.1 (<0.01)	8.0 (<0.20)	0.1 (<0.01)
99% Acetic Acid No chloride added	0.1 (<0.01)	1.4 (0.04)	0.1 (<0.01)
	+250 ppm Cl- as HCl	8.8 (0.22)	10.6 (0.27)

Table III

Nitric Acid Solution	Corrosion Rates Mils Per Year (mm/a)		
	AL 29-4C®	Type 316	Type 304
65%	6.1 (0.15)	17.6 (0.45)	10.3 (0.26)

Table IV. Comparative data on critical crevice and pitting temperatures in an acidified chloride environment for several stainless steels

Alloy	Composition (Wt.%)			CCCT ¹ °F (°C)	CPT ² F (°C)
	Cr	Mo	N		
Type 304	18.0	--	0.06	<27.5 (<2.5)	--
Type 316	16.5	2.1	0.05	<27.5 (<2.5)	59 (15)
Type 317	18.5	3.1	0.06	35 (1.7)	66 (19)
Alloy 904L	20.5	4.5	0.05	68 (20)	104 (40)
AL-6XN®	20.5	6.2	0.22	110 (43)	176 (80)
AL 29-4C®	29.0	4.0	0.02	129 (54)	167 (75)

¹Critical Crevice Corrosion Temperature (CCCT) based on ASTM G-48B (6% FeCl₃ for 72 hours with crevices).

²Critical Pitting Temperature (CPT) based on ASTM G-48A (6% FeCl₃ for 72 hours without crevices).

SERVICES HISTORIES			
Component	Environment	Previous Experience	AL 29-4C® -- Service-to-Date
Residential & Commercial High Efficiency Furnace	Condensing flue gas	Type 304 stainless steel pitted	Continuous successful service since 1983
Mid-Efficiency Boiler	Condensing gas	Carbon steel corroded	Successfully installed for 5 years
Rigid Vent Pipe	Condensing gases, thermal expansion	Plastic pipe cracked & separated	Successful service since mid-1980s
Flexible Chimney Liner	Condensing flue gas	Aluminum & conventional stainless steel corroded	Successful service since mid-1980s
Hot Water Heating Tubular Exchanger	Stress corrosion cracking	Type 316 stainless cracked	In service since 1988

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3. "Technology Development for Corrosion Resistant Condensing Heat Exchangers," Final Report GRI-85/0282 prepared by *Battelle-Columbus Division* under sponsorship of *Gas Research Institute*.

4. "Condensing Heat Exchanger Systems for Residential/Commercial Furnaces and Boilers," Prepared by *Battelle-Columbus Division* for *Brookhaven National Laboratory* under contract with the U. S. Dept. of Energy, October, 1985.
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6. G. H. Stickford and B. Hindin, "Long-Term Corrosion Measurements in Condensing Heat Exchangers," prepared by *Battelle-Columbus Division* under sponsorship of *Gas Research Institute*.
7. "Consumer Advisory -- Plastic Vents Safety Order Issued:" *Ontario Ministry of Consumer and Commercial Relations* September 12, 1995.

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