AL 29-4C® Alloy For Heating and Ventilating

Stainless Steel
(UNS S44735)

TYPICAL COMPOSITION

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt. Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.02</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.50</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.03</td>
</tr>
<tr>
<td>Sulfur</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.35</td>
</tr>
<tr>
<td>Chromium</td>
<td>29</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.30</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>4</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.02</td>
</tr>
<tr>
<td>Titanium+Columbium (Niobium)</td>
<td>0.6</td>
</tr>
<tr>
<td>Iron</td>
<td>Balance</td>
</tr>
</tbody>
</table>

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 developed by ATI 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.

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 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*


*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® Alloy for 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 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 (UNS N08367) has been used in conjunction with lighter gage AL 29-4C alloy.
AL 29-4C® Alloy for 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 alloy 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.

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

The AL 29-4C alloy must only be welded with inert gas shielding techniques such as gas tungsten arc or gas metal arc processes. For weld procedures such as seal welding of tubes to tube sheets 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

<table>
<thead>
<tr>
<th>Condition</th>
<th>(CCCT) ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill Annealed</td>
<td>129 F (54 C)</td>
</tr>
<tr>
<td>As-Welded</td>
<td>125 F (52 C)</td>
</tr>
</tbody>
</table>

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.

Data are typical, are provided for informational purposes, and should not be construed as maximum or minimum values for specification or for final design, or for a particular use or application. The data may be revised anytime without notice. We make no representation or warranty as to its accuracy and assume no duty to update. Actual data on any particular product or material may vary from those shown herein TM is trademark of and ® is registered trademark of ATI Properties, Inc. or its affiliated companies. ® The starburst logo is a registered trademark of ATI Properties, Inc. SEA-CURE is a registered trademark of Plymouth Tube Company © 2012 ATI. All rights reserved.
**AL 29-4C® For Heating and Ventilating**

**Technical Data Sheet**

**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**

<table>
<thead>
<tr>
<th>Acetic Acid Solution</th>
<th>Corrosion Rates Mils Per Year (mm/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AL 29-4C®</td>
</tr>
<tr>
<td>66% Acetic Acid +100 ppm Cl- as Hc</td>
<td>0.1 (&lt;0.01)</td>
</tr>
<tr>
<td>99% Acetic Acid No chloride added +250 ppm Cl- as HCl</td>
<td>0.1 (&lt;0.01)</td>
</tr>
<tr>
<td></td>
<td>8.8 (0.22)</td>
</tr>
</tbody>
</table>

Data are typical, are provided for informational purposes, and should not be construed as maximum or minimum values for specification or for final design, or for a particular use or application. The data may be revised anytime without notice. We make no representation or warranty as to its accuracy and assume no duty to update. Actual data on any particular product or material may vary from those shown herein. TM is trademark of and ® is registered trademark of ATI Properties, Inc. or its affiliated companies. © 2012 ATI. All rights reserved.

 Allegheny Technologies Incorporated
1000 Six PPG Place
Pittsburgh, PA 15222-5479 U.S.A.
www.ATImetals.com
Table III

<table>
<thead>
<tr>
<th>Nitric Acid Solution</th>
<th>Corrosion Rates Mils Per Year (mm/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AL 29-4C&lt;sup&gt;®&lt;/sup&gt;</td>
</tr>
<tr>
<td>65%</td>
<td>6.1 (0.15)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Composition (Wt.%)</th>
<th>CCCT&lt;sup&gt;1&lt;/sup&gt; °F (°C)</th>
<th>CPT&lt;sup&gt;2&lt;/sup&gt; °F (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 304</td>
<td>18.0 -- 0.06</td>
<td>&lt;27.5 (&lt;-2.5)</td>
<td>--</td>
</tr>
<tr>
<td>Type 316</td>
<td>16.5 2.1 0.05</td>
<td>&lt;27.5 (&lt;-2.5)</td>
<td>59 (15)</td>
</tr>
<tr>
<td>Type 317</td>
<td>18.5 3.1 0.06</td>
<td>35 (1.7)</td>
<td>66 (19)</td>
</tr>
<tr>
<td>Alloy 904L</td>
<td>20.5 4.5 0.05</td>
<td>68 (20)</td>
<td>104 (40)</td>
</tr>
<tr>
<td>AL-6XN&lt;sup&gt;®&lt;/sup&gt;</td>
<td>20.5 6.2 0.22</td>
<td>110 (43)</td>
<td>176 (80)</td>
</tr>
<tr>
<td>AL 29-4C&lt;sup&gt;®&lt;/sup&gt;</td>
<td>29.0 4.0 0.02</td>
<td>129 (54)</td>
<td>167 (75)</td>
</tr>
</tbody>
</table>

1 Critical Crevice Corrosion Temperature (CCCT) based on ASTM G-48B (6% FeCl<sub>3</sub> for 72 hours with crevices).
2 Critical Pitting Temperature (CPT) based on ASTM G-48A (6% FeCl<sub>3</sub> for 72 hours without crevices).

SERVICES HISTORIES

<table>
<thead>
<tr>
<th>Component</th>
<th>Environment</th>
<th>Previous Experience</th>
<th>AL 29-4C&lt;sup&gt;®&lt;/sup&gt; -- Service-to-Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential &amp; Commercial High Efficiency Furnace</td>
<td>Condensing flue gas</td>
<td>Type 304 stainless steel pitted</td>
<td>Continuous successful service since 1983</td>
</tr>
<tr>
<td>Mid-Efficiency Boiler</td>
<td>Condensing gas</td>
<td>Carbon steel corroded</td>
<td>In-service since early 1990s</td>
</tr>
<tr>
<td>Rigid Vent Pipe</td>
<td>Condensing gases, thermal expansion</td>
<td>Plastic pipe cracked &amp; separated</td>
<td>Successful service since mid-1980s</td>
</tr>
<tr>
<td>Flexible Chimney Liner</td>
<td>Condensing flue gas</td>
<td>Aluminum &amp; conventional stainless steel corroded</td>
<td>Successful service since mid-1980s</td>
</tr>
<tr>
<td>Hot Water Heating Tubular Exchanger</td>
<td>Stress corrosion cracking</td>
<td>Type 316 stainless cracked</td>
<td>In service since 1988</td>
</tr>
</tbody>
</table>

Data are typical, are provided for informational purposes, and should not be construed as maximum or minimum values for specification or for final design, or for a particular use or application. The data may be revised anytime without notice. We make no representation or warranty as to its accuracy and assume no duty to update. Actual data on any particular product or material may vary from those shown herein. TM is trademark of and ® is registered trademark of ATI Properties, Inc. or its affiliated companies. © The starburst logo is a registered trademark of ATI Properties, Inc. SEA-CURE is a registered trademark of Plymouth Tube Company © 2012 ATI. All rights reserved.
REFERENCES


