# AlcoTec Aluminum Wire & Equipment Technical Guide

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The **AlcoTec® advantage.**

At AlcoTec®, aluminum welding isn’t just part of our business, it’s our only business. Since 1984, AlcoTec aluminum wire has been world renowned for quality, consistency, and performance.

And premium aluminum wire is just the start of what we offer. Our goal is to help you work smarter, faster, and better. With continuous innovation, we maximize your productivity while minimizing your costs by:

- Providing service and support that goes the extra mile to keep you up and running
- Helping you take your aluminum welding skills to the next level through expert training
- Becoming the ultimate partner you can trust for years to come

At AlcoTec, integrity is just as important to us as the quality of our product. We strive to treat everyone with the utmost respect. We measure our success by the number of long-term customers who trust us and value what we bring to the table. And we appreciate it when our customers say how much they like working with us.

We invite you to get to know AlcoTec’s products, equipment, and technical services.

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**Our mission:** To provide our customers with the most cost-effective solutions for their welding and cutting applications. Through technological leadership, the most reliable products and deliveries, and continuous improvement of our processes, we will delight our customers, employees, shareholders, and community.

**Our values:** Integrity, Progress, Quality, Leadership, and Teamwork.

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**“We take the concerns of our customers to heart!”**

– Todd Peters, Operations Manager, AlcoTec Wire Corporation

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**Environmental Health and Safety**

At AlcoTec, we put a heavy emphasis on environmental health and safety, and are constantly looking for ways to improve our operations. Our facilities and products meet or exceed all applicable governmental requirements and standards. We educate and encourage our employees to comply with EHS policies.

AlcoTec is a subsidiary of ESAB Group, Inc., - the first global company to achieve both ISO 14001 (1999) and OHSAS 18001 (2006) certifications. Furthermore, we are proud to be ISO 9001 certified.
No one knows aluminum welding better.

We are your tried and true aluminum welding experts. Unlike other manufacturers who deal with multiple welding processes, we specialize solely in aluminum. This allows us to provide an unmatched array of services from experienced engineers and technicians - expertise you won’t find anywhere else.

As an AlcoTec partner, help is always available. Our Customer Service Specialists work directly from our manufacturing facility, so you’ll work with a factory-based technician who can help you with everything from troubleshooting to checking on the status of an order. You can even arrange a consultation with one of our industry-leading Metallurgical or Welding Engineers.

Our team of Field Specialists have been technically trained to personally solve simple problems to complex issues. You can reach our Service Team by phone, email, Facebook, or our website. Either way, you can look forward to a prompt, thorough response to your question.

“I absolutely recommend AlcoTec. They’re more than a wire company. They fix issues that aren’t really their problems!”

– Rusty Beckner, AlcoTec customer

Get the most from your application

As a specialized process, there are many factors to consider when welding aluminum that will determine the effectiveness of your application. This section details some of the more critical technical specifications that will help you get the most from your aluminum welding application.
The Aluminum Association uses a four digit numbering system for designating wrought aluminum and wrought aluminum alloys. The image above shows the wrought alloy groups as well as a few examples of common products from each group. The significance of each number is described below.

1st Digit – Identifies the major alloying element.
2nd Digit – Identifies the rendition of an alloy. For example, 5356 is the 3rd rendition of the original base alloy 5056.
3rd and 4th Digits:
- In the 1XXX group, the last two digits indicate the minimum aluminum percentage. For example, alloy 1188 has a minimum purity of 99.88% aluminum. Alloy 1350 has a minimum purity of 99.50% aluminum.
- In the 2XXX – 8XXX groups, the last two digits serve merely as counters. For example, 3004 was the next manganese alloyed chemistry after 3003.

Filler Alloys: Chemical Composition Limits & Physical Properties

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si (min)</th>
<th>Fe (min)</th>
<th>Cu</th>
<th>Mn (min)</th>
<th>Mg (min)</th>
<th>Zn (min)</th>
<th>Cr (min)</th>
<th>Ti (min)</th>
<th>Others (1)</th>
<th>Aluminum (Al) %</th>
<th>Approximate Melting Range, °F</th>
<th>Density lbs/in³</th>
<th>Post (4)</th>
<th>Anodize Color &amp; Tint</th>
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<td>0.10</td>
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<td>0.18</td>
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<td>0.18</td>
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<td>0.10</td>
<td>0.10</td>
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<td>0.10</td>
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<td>0.40</td>
<td>0.40</td>
<td>0.10</td>
<td>0.10</td>
<td>1200-1215</td>
<td>0.18</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Conversion Factors

- **Fraction**: Decimal, mm, ft/lb, m/kg, Approximate Wire Gauge
- **Convert From**: Convert To, Multiply By
  - inches to millimeters: 25.4
  - millimeters to inches: 0.03937
  - square inches to square millimeters: 645.2
  - square millimeters to square inches: 0.001552
  - fluid ounces to millimeters: 29.57
  - millimeters to fluid ounces: 0.03381
  - ounces to grams: 28.35
  - grams to ounces: 0.03527
  - pounds to kilograms: 45.36
  - kilograms to pounds: 2.205
  - Newtons/mm to pounds/inch: 145.04
  - pounds/inch to Newtons/mm: 0.006895

Heat Treatable & Non-Heat Treatable Base & Fillers

The image shows the wrought alloy groups as well as a few examples of common products from each group.
Welded Joint Strength

Typically, the as-welded tensile strength of a groove weld is determined by the condition of the heat-affected zone (HAZ) of the base material.

Fillet welds are usually not diluted significantly by the base metal. Therefore, the shear strengths of fillet welds are largely determined by the properties of the filler alloy and not necessarily by the condition of the HAZ of the base.

Typical Shear Strength - Fillet Welds

<table>
<thead>
<tr>
<th>Filler Alloy</th>
<th>Longitudinal Shear Strength (KSI)</th>
<th>Transverse Shear Strength (KSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1100</td>
<td>7.5</td>
<td>7.5</td>
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<tr>
<td>2319</td>
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<td>4043</td>
<td>11.5</td>
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<td>4643</td>
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<td>5554</td>
<td>15.0</td>
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</tr>
<tr>
<td>5654</td>
<td>12.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Conservative values based on bare minimum fusion. Multiple factors influence shear strength. Contact AlcoTec to discuss your specific application.

Typical Tensile Properties - Groove Welds

<table>
<thead>
<tr>
<th>Base Alloy</th>
<th>Approximate Melting Range °F of Base Alloy</th>
<th>Base Alloy Properties</th>
<th>As Welded Properties</th>
<th>Post-Weld Heat Treated &amp; Aged</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tensile Strength psi x 10^3 (1)</td>
<td>Yield Strength psi x 10^3 (2)</td>
<td>Elongation % in 2 in.</td>
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<tr>
<td>1060-H16</td>
<td>1195-1215</td>
<td>16 15 8</td>
<td>ER1188 10 5 29</td>
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<tr>
<td>1100-H16</td>
<td>1190-1215</td>
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<td>ER1100 13 6 29</td>
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<td>1350-H16</td>
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<tr>
<td>5500-H24</td>
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<td>28 24 8</td>
<td>ER6356 23 12 18</td>
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<td>33 28 12</td>
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<td>35 (3) (4)</td>
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<td>1090-1205</td>
<td>45 40 12</td>
<td>ER5356 30 19 11</td>
<td>—</td>
</tr>
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</table>

Typical properties of gas-shielded, arc welded groove joints in aluminum alloys.

(1) Reduced section tensile strength.

(2) 0.2% offset in 2 in. gauge length.

(3) Postweld aged only.

(4) Data assumes sufficient dilution of base.
Weld Control Characteristics

Parameter Changes & Current Density

Increasing arc voltage decreases:
- Wire to work piece gap
- Energy distribution width

Recommendations
- Root Pass: Shorter Arc
- Finish Pass: Longer Arc
- 5XXX Alloys: Shorter Arc, Lower Arc Voltage, Higher Amperage
- 4XXX Alloys: Longer Arc, Higher Arc Voltage, Lower Amperage

Increasing arc voltage reduces arc energy concentration

\[
0.047 \text{ in. diameter} = 0.0235 \text{ in.}^2 \times \pi = 0.0017 \text{ in.}^2 \text{ section}
\]
Technical Services

Backling Bars

What is the best backing bar material for an aluminum groove weld?

There really isn’t a “best” material for a backing bar. To determine the most appropriate material, you must consider a few things:

Is the backing bar going to be permanent or temporary?

For a permanent backing bar the answer is easy—use the same alloy as one of the groove weld components.

For temporary bars, consider these points:

- Hard-coat anodized aluminum, copper, stainless steel, and ceramic can all be used.
- Don’t weld directly on the backing material. A temporary bar is there only to support the root reinforcement, and the backing material may contaminate the weld.
- Hard-coat anodized aluminum works very well. The thermal properties are the same as the base material; the groove is easily machined.
- Copper has a tendency to cool the weld more quickly than the other materials (copper cools quickly).
- Stainless Steel has a tendency to heat up and cool the weld more slowly (stainless cools slowly).
- Ceramic is available with adhesive for attaching directly to the base material, but is also very fragile.

Should the groove be square or rounded in a temporary backing bar?

Typically, a square cut groove is going to provide better results than a rounded (or bowl shaped) groove. The images below show the result of a square cut in the temporary backing bar, the joint design, and the cross section of the weld achieved.

Excerpt from AWS D1.2: 2014

When conducting bend tests, care must be taken to ensure the proper bending criteria are used. The following steps should be taken to help ensure accurate bend test results.

1. Ensure proper test jig is used:

- **Wrap-Around Guided Bend Jig** (Preferred for Aluminum)

  - Sanding lines should be perpendicular to the weld (in-line with the bending direction)

- **Plunger-Style Test Jig** (Not Recommended for Aluminum)

  - A radius should be applied to the edges of each bend specimen per applicable specification

2. Review applicable code/specification to ensure the proper bend radius is used. Also note that this is where the base and filler alloy combination affects the bend radius and sample thickness.

3. Ensure samples are prepared properly, according to the applicable code/specification, prior to bending.

### Bend Testing Aluminum

<table>
<thead>
<tr>
<th>Thickness of Specimen</th>
<th>Bend Mandrel Diameter</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8 t</td>
<td>1-1/2</td>
<td>M21 and M22</td>
</tr>
<tr>
<td>1/8 t (&lt;1/8)</td>
<td>2-1/16</td>
<td>M23* or F23 Welds</td>
</tr>
<tr>
<td>3/8 t</td>
<td>2-1/2</td>
<td>M25 and Annealed M23*</td>
</tr>
</tbody>
</table>

*Note: Temper condition can also have an influence on the testing criteria.*
Aluminum welding equipment demands attention to detail as feedability affects performance and productivity. Below are areas of concern that can improve feedability, reduce downtime, and minimize maintenance costs.

**Correct Contact Tip Size (I.D. and length)**
- I.D. 10% larger for hard wire
- I.D. 20% larger for soft wire
- Longer is better
- Remove burrs from tip entrance
- Polish, clean, and inspect contact tips

**Drive Rolls**
- U-groove type reduces shavings
- Clean and polish rolls regularly
- Inspect for sharp edges, embedded particles, and misalignment
- If V-groove are used on one side, use a flat on the other
- V-grooves rollers with an angle > 60 degrees
- Plastic rolls can wear unevenly causing wire distortion

**Gun Liners and Wire Guides**
- Teflon is soft and can hold embedded particles
- Nylon is tough, holds its shape and reduces embedded particles
- Right size liner
- Cut to the proper length
- Plastic guides such as Nylon work to reduce shavings

**Torch and Nozzles**
- Straight nozzles aspirate less air than tapered
- Water-cooled torches are more efficient
- Curved torches require more drive force
- Overheated torches can melt liners and ruin parts
- Aluminum and argon lower the duty cycle of torches (for torches rated with low voltage and CO2 gas)
- Push/pull for whip lengths over 9 ft. (3 m)
- Slave in the rear push/pull reduces liner wear and feeding issues

---

**Possible Solutions**
1. Bring material into work space 24 hours prior to usage. This allows the temperatures to stabilize.
2. Store filler material in an oven.
3. Store base material vertically allowing air flow to help the material temperature to stabilize.

---

### Atmospheric Conditions Affect Weld Quality

Many fabricators experience welding problems at different times of the year. Moisture (H2O) is a prime source of hydrogen. At arc temperatures, water breaks down releasing hydrogen atoms that cause porosity in weldments. Shielding gas supplies are controlled to very low moisture content (-70°F dewpoint or lower). Likewise, the atmospheric conditions in a fabricating facility need to be controlled to prevent moisture condensation from forming on electrode or base metal.

#### Relative Humidity vs. Dew Point

<table>
<thead>
<tr>
<th>Relative Humidity %</th>
<th>∆t °F Air-Metal</th>
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<tbody>
<tr>
<td>87</td>
<td>3.6</td>
<td>1.1</td>
</tr>
<tr>
<td>75</td>
<td>7.2</td>
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</tr>
<tr>
<td>66</td>
<td>10.8</td>
<td>3.3</td>
</tr>
<tr>
<td>57</td>
<td>14.4</td>
<td>4.4</td>
</tr>
<tr>
<td>50</td>
<td>18.0</td>
<td>5.6</td>
</tr>
<tr>
<td>44</td>
<td>21.6</td>
<td>6.6</td>
</tr>
<tr>
<td>38</td>
<td>25.2</td>
<td>7.9</td>
</tr>
<tr>
<td>34</td>
<td>28.8</td>
<td>8.8</td>
</tr>
<tr>
<td>30</td>
<td>32.4</td>
<td>9.9</td>
</tr>
<tr>
<td>26</td>
<td>36.0</td>
<td>11.0</td>
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<td>23</td>
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<tr>
<td>21</td>
<td>43.2</td>
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</tr>
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<td>15.4</td>
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</tbody>
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Example: If the relative humidity in the weld area is 75%, the base metal and electrode must be no colder than 7.2°F below the air temperature to prevent moisture condensation.

---

**Possible Solutions**
1. Bring material into work space 24 hours prior to usage. This allows the temperatures to stabilize.
2. Store filler material in an oven.
3. Store base material vertically allowing air flow to help the material temperature to stabilize.

---

### Feedability

- A - CONTACT TIP
- B - JUMPER LINER
- C - CONDUIT
- D - LINER
- E - OUTLET GUIDE
- F - "U" GROOVE DRIVE ROLLS
- G - INLET GUIDE
- H - ALUMINUM ELECTRODE
- I - ELECTRODE SPOOL

---

(1) AlcoTec offers a contact tip polishing kit (part no. TIP-TUBE)
(2) AlcoTec offers a drive roll polishing kit (part no. DRV-ROLLPOLISH)

---

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3. Store base material vertically allowing air flow to help the material temperature to stabilize.
Welders completing groove welds often end up with excessive face reinforcement on their welds. Whether they just want to make sure the joint is filled in or they think it makes the weldment “stronger”, it typically causes more potential for harm than good. Excessive face reinforcement on a groove weld will typically create a larger stress riser which may increase the odds of the weldment cracking because of fatigue. Note the location of the crack in the weld image below.

**Excessive Face Reinforcement**

By increasing the reinforcement angle of the weld metal as shown in these images, the maximum amount of stress the assembly could withstand almost doubled. Additionally, removal of the reinforcement can restore fatigue performance to near un-welded condition in non heat-treatable alloys or re-heat-treated surfaces.

A weld essentially becomes a new alloy made up of the base and filler alloys. Dilution is the amount of base alloy that mixes with the filler alloy to create the new weld alloy. There are multiple factors that affect the amount of base dilution into the weld puddle. Although the welding parameters can change the dilution ratio, the easiest way to actually control it is by modifying the joint design (see images below).

**Dilution Ratios of Joints**

Depending on the alloys involved, simply changing the joint design may be enough to change the tensile strength of an as-welded groove assembly. The image below shows the theoretical difference in dilution ratios by modifying the joint design from a square butt to a single V-groove. The amount of base metal that is diluting the filler alloy is reduced in the single V, making the overall magnesium content of the new weld alloy significantly higher.

Depending on the other variables involved, this may be all that is needed to go from just missing the minimum tensile strength to achieving it regularly (and with room to spare). Another benefit of reducing the amount of base metal dilution is that the probability of stress cracking is typically reduced.

**Weld Composition: Dilution Effect**

- Base Plate 6061
- Filler Metal 5356
- 1.7% Mg
- 20% Filler Metal 80% Base Metal
- 3.2% Mg
- 60% Filler Metal 40% Base Metal
Avoid Plasma/Laser Cut Micro Cracks in Welds

Micro-cracks are potential crack starters in aluminum welds.

For heat treatable aluminum alloys, 1/8 in. (3 mm) of material shall be removed by machining from plasma arc and laser cut edges that will be welded. - AWS D1.2

Heat-Treatable and Non Heat-Treatable Alloys & the Heat Affected Zone (HAZ)

Aluminum alloys can be separated into one of two groups, heat-treatable and non heat-treatable. All aluminum alloys can be strengthened through cold working operations, but only the heat-treatable alloys can be strengthened through thermal processes. Because of this characteristic, the heat from arc welding processes affects each group differently.

Most aluminum alloys are annealed to their softest condition when they reach approximately 650°F (350°C). Considering that aluminum melts somewhere in the area of 1100-1200°F (600-650°C) it can be expected that portions of the Heat Affected Zone (HAZ) will reach the annealing temperature during an arc welding process. This results in the weld assembly enduring a thermal cycle that can greatly change the properties of the weldment.

The completed weld assembly can be broken up into three distinct areas:

1. Weld Metal
2. Heat Affected Zone (HAZ) adjacent to the weld
3. Base material beyond the HAZ which has been unaffected by the welding operation.

Heat Treatable

All of the 2XXX, 6XXX, 7XXX, and a few of the 4XXX series alloys are heat-treatable. This means that these alloys can be strengthened, not only through cold working, but also through thermal processes.

In the case of the heat-treatable alloys, the heat affected zone presents some interesting dynamics. Although the HAZ will see the annealing temperature during the arc welding process, it is often not fully annealed. As a result of the rate at which the assembly cools, a partial heat treatment typically occurs, which generally results in tensile strengths slightly higher than the annealed strength of the alloy.

However, the strength of the HAZ can also be negatively affected by the amount of time it spends at the elevated temperatures encountered during arc welding. This is the “time at temperature” relationship, which drives the resultant strength of the weldment. The longer the weldment is at elevated temperatures, the weaker the HAZ is typically expected to be. This “overheating” phenomenon can actually result in a groove weld tensile strength below the minimum required.

Non Heat-Treatable

This group includes all of the 1XXX, 3XXX, 5XXX, and the remainder of the 4XXX series alloys. These alloys can only be strengthened through strain hardening. Thermal treatments cannot be used to strengthen these aluminum alloys.

The heating of the HAZ, which takes place during the arc welding operation, is sufficient to anneal the base material within the HAZ area, and return it to the alloy’s softest condition. Unlike the heat-treatable alloys, non-heat treatable alloys do not generally require extended amounts of time at elevated temperatures to become annealed.

Annealing eliminates the strain hardening as well as the microstructure that is developed as a result of cold working. For this reason, the minimum tensile strength requirements for as-welded non-heat treatable alloys, regardless of the original work hardened temper, is based on the annealed strength of the base alloy.

Non-Weldable Alloys

There are also a few heat-treatable alloys, which are considered to be “non-weldable”. It is not that they cannot be welded, but that they should not be welded if there is ANY LIABILITY involved with the finished product. Due to the chemistry of these alloys, arc welding temperatures produce a microstructure that will lead to grain boundary cracking and there is nothing that can be done to prevent it.

The two most common alloys in this group are 2024 and 7075, but there are many others.

Summary

When designed and welded properly, the tensile strength of a groove weld will be determined by the HAZ. While the heat from the arc welding process will affect both groups of alloys, the reduction in strength in the HAZ will be fairly predictable in the non-heat treatable alloys. Since the heat-treatable alloys respond uniquely to the heat, the resulting HAZ strength can be less predictable. In order to obtain consistent results, the use of qualified weld procedures is highly recommended.
Considerations When Repairing Aluminum Structures

Identification of the Base Alloy

Probably the most important, and usually the first step in the repair operation, is identifying the aluminum base alloy being repaired. If the base alloy type is unknown, one could contact the original manufacturer of the component to establish the aluminum base material type. If the base material type is not available through a reliable source, it is impossible to select a suitable welding procedure.

There are many different types of aluminum alloys, some have very good weldability and others have extremely poor weldability. Unfortunately, if the base material type is not known, or unavailable, chemical analysis is the only one reliable way of establishing the exact type of aluminum alloy. A small sample of the base material must be sent to a reliable aluminum-testing laboratory, and a chemical analysis must be performed. Generally, the chemistry can then be evaluated and a determination as to the most suitable filler alloy and the welding procedure can be made.

Cleaning and Material Preparation Prior to Welding

It is very important to clean the repair area completely prior to performing the weld repair. This is typically achieved using a degreasing solvent to remove hydrocarbons followed by stainless steel brushing to remove the aluminum oxide. More aggressive filing, or chemical cleaning, may be required for some applications.

In situations where it is necessary to remove existing weld or base material in order to conduct the repair, you need to consider the methods available to perform this operation as well as their effect on the finished weld. If you need to remove a crack in the surface of a weld prior to re-welding, you must use a method that will not contaminate the base material to be welded. Care should be taken when using grinding discs as some have been found to contaminate the base material by depositing particles into the surface of the aluminum. Routting and chipping with carbide tools is often found to be a successful method of material removal.

Base Material Strength Reduction After Welding

There may be considerations relating to the effect of the heating of the base material during the repair welding process. Aluminum alloys are divided into two groups:

1. Heat-treatable
2. Non heat-treatable

Typically, the non-heat-treatable alloys are used in a strain-hardened condition and the heat-treatable alloys are usually used in one heat-treated form or another.

During the welding process, the heat introduced to the aluminum base will generally reduce the strength of the base material in the heat-affected zone (HAZ).

Shielding Gas for Arc Welding Aluminum

Shielding Gas Functions
- Provides a plasma for commutation of current
- Protects the weld pool from reaction with air environment
- Provides cleaning action, which partially removes the aluminum oxide from the base material (DCEP)

Properties of Shielding Gases

<table>
<thead>
<tr>
<th>Argon</th>
<th>Helium</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>Good arc initiation and stability</td>
<td>Narrow weld root width</td>
</tr>
<tr>
<td>More effective shielding</td>
<td>Poor cleaning</td>
</tr>
<tr>
<td>Lower cost</td>
<td>Poor arc initiation and stability</td>
</tr>
<tr>
<td>Good cleaning</td>
<td>Higher cost</td>
</tr>
<tr>
<td></td>
<td>Higher flow rates required</td>
</tr>
</tbody>
</table>

Cracked repair weld due to improperly preparing the repair area.
Easy Weld Quality Tests

Lack of fusion and porosity can be considered the two most common discontinuities in aluminum welds. If you’re making changes to your process to reduce these items, you’ll want to be able to check your weld quality right away. Below are a few methods you can use for quick weld quality checks.

Fillet Welds
You can easily check fillet welds for both lack of fusion and porosity using the fillet fold over test. Weld one side only of a tee joint and then fold the weldment over as shown here. If the weld breaks, examine the internal structure of the weld metal (examples are shown below).

Porosity will show up as very shiny, spherical inclusions.

Lack of fusion is evident when the sharp edge of the vertical component can still be seen under the weld metal.

When complete fusion is achieved, the edge of the vertical component will be melted away by the weld metal.

Complete Fusion

Lack of Fusion

Groove Welds
Since groove welds cannot simply be folded over, a nick-break procedure can be done to examine the internal weld structure.

Porosity will show up as very shiny, spherical inclusions.

Lack of fusion/void

Sound weld metal

Porosity

Lack of fusion/void

Easy Weld Quality Tests

An easy way to examine the cross-sectional profile of a weld is to perform a “poor-man’s etch”. This can be done on fillet and groove welds. It involves cutting the weldment to expose the cross section and polishing it as smoothly as possible. Then warm up the sample (warm to the touch is sufficient) and spray the face to be etched with Easy Off® oven cleaner. The chemical in this cleaner (sodium hydroxide) will etch the surface after about 20-30 seconds. Rinse the sample, dry it (compressed air cans work nicely), and then dust it with a clear lacquer.

Use a saw to notch each side of a sample taken from a groove weld assembly, as shown.

Clamp one end in a vice and strike the other end with a hammer to break the sample.

Porosity

Lack of fusion/void

Sound weld metal
Weld Cracking

Common Causes and Cures
There are two types of cracks that can occur in aluminum welds: stress cracks and hot cracks.

Stress cracks occur when the weld is simply unable to withstand the forces applied to it. This can be due to a poor joint design that is welded as designed, a weld that is just not strong enough for the application (not designed properly) or an improper weld. Images 1A and 1B show fillet weld examples. Image 1A shows the profile of an acceptable weld. Image 1B shows an excessively concave weld that failed through the effective throat (refer to Image 2). If the weld is inadequate for any of the above mentioned reasons, it is very possible it will not withstand service conditions.

Hot cracks are a result of the chemistry. It can be the chemistry of the base alloy, the filler alloy or the combination making the weld itself. The graph that follows shows the hot cracking sensitivity for some of the most common aluminum alloy groups; Silicon (4XXX), Copper (2XXX), Magnesium (5XXX), and Magnesium-Silicide (6XXX).

Different alloying elements affect the melting temperatures and ranges of aluminum. Alloys with a larger liquid to solid range will have a greater tendency to hot crack. The graph shows where each chemistry’s peak of crack sensitivity will be based on the percentage of the major alloying element.

Crater cracks may occur as a result of stress and/or chemistry. Crater cracks that are caused by stress typically occur when the weld termination point (crater) has a smaller cross section than the rest of the weld and simply cannot withstand the forces applied during the solidification process (see Images 3A and 3B).

Because of their chemistry, some base materials are more susceptible to hot cracking than others. Welds made on these alloys need to be “flooded” with enough of the filler alloy to change the chemistry and move it away from the crack sensitive range. Since the crater is typically smaller in cross-section, there is often not enough filler alloy added to change the weld pool chemistry and it becomes prone to hot cracking, even though the remainder of the weld is not.

Since weld cracks can be the result of stress, chemistry, or a combination, determining the root cause can be difficult. For assistance in troubleshooting weld cracking concerns, please contact AlcoTec Technical Services at 1-800-228-0750.

Common Causes and Cures

Weld Cracking

Alloy Content vs. Crack Sensitivity

<table>
<thead>
<tr>
<th>Alloy Composition</th>
<th>Relative Crack Sensitivity</th>
</tr>
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<tbody>
<tr>
<td>Al-Si</td>
<td></td>
</tr>
<tr>
<td>Al-Cu</td>
<td></td>
</tr>
<tr>
<td>Al-Mg</td>
<td></td>
</tr>
<tr>
<td>Al-Mg2Si</td>
<td></td>
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</table>

| Composition of Weld - Percent Alloying Element |

24
One of the most frequently asked aluminum welding questions is "What filler alloy do I use for welding 6061?". The AlcoTec filler alloy chart has several suggested options of filler alloys to use with 6061. From a chemistry stand point, there are very few options that are not acceptable. However, there are a few elements to consider when choosing the most appropriate filler alloy to use.

1. **Ease of welding** - this is the relative freedom from weld cracking. By use of hot cracking sensitivity curves (see page 25) for the various aluminum alloys, and through the consideration of dilution between filler alloy and base alloy, we can establish the filler alloy/base alloy crack sensitivity rating.

2. **Strength of welded joint** - consideration of the tensile strength of groove welds and shear strength of fillet welds, when welded with different filler alloys, can prove to be extremely important during welding design. Different filler alloys, which may exceed the as-welded tensile strength of the base material, can be significantly different in shear strength performance.

3. **Ductility** - a consideration if forming operations are to be used during fabrication, and may also be a design consideration of service if fatigue and/or shock loading are of importance.

4. **Corrosion resistance** - a consideration for some environmental conditions and are typically based on exposure to fresh and salt water.

5. **Sustained temperature services** - the reaction of some filler alloys at sustained elevated temperature (above 150°F). This may promote premature component failure due to stress corrosion cracking.

6. **Color match** - base alloy and filler alloy color match after anodizing can be of major concern in some cosmetic applications.

7. **Post weld heat treatment** - the ability of the filler alloy to respond to post weld heat treatment associated with filler alloy chemistry and joint design.

These are all elements that must be considered when selecting a filler alloy for welding on 6061. It is the application of the completed weldment that will drive which alloy should be used for welding.

### Performance Improvement - Increasing Wire Diameter

**What affect does increasing wire diameter have on the welding process?**

Some advantages of increasing wire diameter are: better fusion/penetration, increased travel speeds, higher deposition rates, lower price per pound, and better feedability.

Due to the physical and mechanical properties of aluminum, it is very feasible to increase wire diameter and either: 1) go faster to increase production rates or, 2) make a larger weld without slowing down. The tables below show the results from using larger wire for each goal. The table layout shows the percent increase between each wire increment as well as the increase if you were to "skip" a level.

#### Common Bead Width

<table>
<thead>
<tr>
<th>Diameter (in.):</th>
<th>.047</th>
<th>.062</th>
<th>.071</th>
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<tbody>
<tr>
<td>Amps</td>
<td>223</td>
<td>274</td>
<td>319</td>
<td>375</td>
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<tr>
<td>Volts</td>
<td>22.5</td>
<td>23</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Wire Feed Speed (ipm)</td>
<td>523</td>
<td>366</td>
<td>295</td>
<td>180</td>
</tr>
<tr>
<td>Bead Width Target (in.)</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Travel Speed (ipm)</td>
<td>26</td>
<td>35.8</td>
<td>42</td>
<td>49</td>
</tr>
<tr>
<td>Percent Increase in Travel Speed</td>
<td>—</td>
<td>37.7</td>
<td>17.3</td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>—</td>
<td>61.5</td>
<td>36.9</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>88.5</td>
</tr>
</tbody>
</table>

#### Common Travel Speed

<table>
<thead>
<tr>
<th>Diameter (in.):</th>
<th>.047</th>
<th>.062</th>
<th>.071</th>
<th>.094</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>225</td>
<td>258</td>
<td>264</td>
<td>375</td>
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<tr>
<td>Volts</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>26</td>
</tr>
<tr>
<td>Wire Feed Speed (ipm)</td>
<td>531</td>
<td>366</td>
<td>271</td>
<td>180</td>
</tr>
<tr>
<td>Travel Speed (ipm)</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Bead Width (in.)</td>
<td>0.422</td>
<td>0.480</td>
<td>0.582</td>
<td>0.688</td>
</tr>
<tr>
<td>Percent Increase in Travel Speed</td>
<td>—</td>
<td>13.7</td>
<td>21.3</td>
<td>18.1</td>
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<tr>
<td></td>
<td>—</td>
<td>—</td>
<td>37.9</td>
<td>43.2</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>62.9</td>
</tr>
</tbody>
</table>

This is just one step toward improving performance and productivity. Other tools and techniques can be found throughout this guide.

### Filler Alloy for Welding 6061-T6

One of the most frequently asked aluminum welding questions is "What filler alloy do I use for welding 6061?". The AlcoTec filler alloy chart has several suggested options of filler alloys to use with 6061. From a chemistry stand point, there are very few options that are not acceptable. However, there are a few elements to consider when choosing the most appropriate filler alloy to use.

- **Ease of welding** - this is the relative freedom from weld cracking. By use of hot cracking sensitivity curves (see page 25) for the various aluminum alloys, and through the consideration of dilution between filler alloy and base alloy, we can establish the filler alloy/base alloy crack sensitivity rating.
- **Strength of welded joint** - consideration of the tensile strength of groove welds and shear strength of fillet welds, when welded with different filler alloys, can prove to be extremely important during welding design. Different filler alloys, which may exceed the as-welded tensile strength of the base material, can be significantly different in shear strength performance.
- **Ductility** - a consideration if forming operations are to be used during fabrication, and may also be a design consideration of service if fatigue and/or shock loading are of importance.
- **Corrosion resistance** - a consideration for some environmental conditions and are typically based on exposure to fresh and salt water.
- **Sustained temperature services** - the reaction of some filler alloys at sustained elevated temperature (above 150°F). This may promote premature component failure due to stress corrosion cracking.
- **Color match** - base alloy and filler alloy color match after anodizing can be of major concern in some cosmetic applications.
- **Post weld heat treatment** - the ability of the filler alloy to respond to post weld heat treatment associated with filler alloy chemistry and joint design.

These are all elements that must be considered when selecting a filler alloy for welding on 6061. It is the application of the completed weldment that will drive which alloy should be used for welding.

### Color Match After Clear Anodize

[Image showing Color Match After Clear Anodize]
The Affect of Texture on Anodizing

What if you have welded a base material with a filler alloy that has an “A” rating for color match, but can still see the weld? When a part is anodized, the oxide layer that is added follows the contour of the part, it does not fill in the valleys to make a level surface. It is not possible to see the actual surface texture without the aid of magnification, but when the light reflects off of the base material, you will see the difference.

The image below shows how the light will pass through the anodized layer and then reflect back through it - this is where the perceived color match comes from. Wrought products have very smooth surfaces where cast products do not. When a rolled or extruded product (wrought) is welded, the weld is actually a cast structure. Since the textures are now different, the light will reflect differently and the weld will still be “visible” even though it is the same color.

Therefore, to make the weld as close to “invisible” as possible, you can add a texture to the entire surface. This can be done using a variety of methods (broad blasting, sand blasting, sanding, etc.).

Color Matching

Accomplished by selecting proper filler alloy and altering surface of the part.

![Light](Smooth Surface) ![Light](Rough Surface)
Aluminum Filler Alloy Chart

**How To Use This Chart**

1. Select base alloys to be joined (one from the side blue column, the other from the top blue row).
2. Find the block where the column and row intersect.
3. This block contains horizontal rows of letters (A, B, C or D) representative of the alloy directly across from them in the filler alloy box at the end of each row. The letters in each line give the A-to-D rating of the characteristics listed at the top of each column (W, S, D, C, T and M (see Legend at right for explanation of each letter)).
4. Analyze the wild characteristics afforded by each filler alloy. You will find that you can "trade off" one characteristic for another until you find the filler that best meets your needs.

**Example**

If joining base alloys 6061 and 5086, first find the box where the 6061 row and the 5086 column intersect. Then notice that there are no ratings for filler alloys 4047/4043, 4145, or 4643. Alloy 4047 provides increased fluidity for welding leak-tight joints, minimizes weld shrinkage and has improved post-weld treatment for high-temperature service. Therefore, it must be decided which attribute has the higher priority.

**NOTES:**

1. The following filler alloys are heat-treatable and can produce higher strength weldments after post-weld solution heat treatment and aging:
   - 2024
   - 6061
   - 7075
   - 6063

2. Alloy 4043/4047 provides increased fluidity for welding leak-tight joints, minimizes weld shrinkage, and has improved post-weld treatment for high-temperature service.

3. An "A" rating for alloy 5083 to 5083 and 5083 to 5456.

4. A "B" rating for strength, but a "A" rating for ductility.
School for aluminum welding.

Aluminum welding is a specialized process. Whether you are transitioning from welding other materials, or you are a seasoned veteran, it is always important to understand the latest technologies and best practices. That is why we have developed a range of services to help improve your welding and your bottom line that are available at the AlcoTec facility – or we'll come to you.

- AlcoTec Weld School: Aluminum Welding Technology Theory & Practice – an international program that provides a hands-on approach to welding aluminum alloys
- Welder Qualification Program
- Welder training
- On-site tailored consulting – assisting in the methodology and process of your application
- Weld procedure development via tailored support or Welding Procedure Specifications (WPS)

Training and certification

AlcoTec’s Weld School program is designed to incorporate both the theoretical and practical, hands-on approach to the welding of aluminum alloys. The classroom instruction includes an understanding of the theory and general characteristics of the various aluminum alloys and tempers.

Register online at alcotec.com/weldschool.

“AlcoTec has a very good quality product. They stand behind it.”

– Joseph Maino, AlcoTec customer
Education

AlcoTec School of Aluminum Welding Technology

AlcoTec’s School of Aluminum Welding Technology: Theory & Practice Program is designed to incorporate both a theoretical and practical approach to welding aluminum alloys.

Designed for welding engineers, product design engineers, and sales personnel, the AlcoTec School of Aluminum Welding Technology Program includes comprehensive classroom instruction combined with hands-on laboratory applications.

In this three-day program, students learn metal preparation, weld procedures, inspection procedures, processes for joining aluminum and much more. AlcoTec’s staff of Metallurgical, Welding, and Quality Engineers and Technicians bring their years of aluminum manufacturing experience to this program, which educates participants in the theory and general characteristics of various aluminum alloys and tempers.

In addition, AlcoTec is pleased to offer the first program for Aluminum Welding Technology designed specifically for welding instructors. The Aluminum Welding Technology Instructor’s Course provides welding instructors with the information and tools they need to effectively introduce their students to aluminum welding.

What You Will Learn

- Metal preparation
- Weld procedures
- Workmanship
- Inspection procedures
- Understanding welding equipment
- Processes for joining aluminum

Who Should Attend

- Welding Engineers
- Welding Supervisors
- Welding Instructors
- Product Design Engineers
- Sales Managers and Representatives

Welder Certification and Qualification

CWIs (Certified Welding Inspectors) are often asked to “certify” welders. However, most of these requests should actually be to “qualify” welders. So, what is the difference?

Certification

According to the AWS (American Welding Society):

“The Certified Welder Program is a performance-based program with no prerequisite courses or certifications required. Final certification will provide “transferable” credentials that you may take with you wherever you go.”

To become “certified”, one has to schedule a visit to an AWS ATF (Accredited Test Facility) and perform the testing there. After the inspection and mechanical testing is complete, the test facility will then submit the documentation to the AWS headquarters for review. If everything is properly completed, and all of the testing is satisfactory, the AWS will issue the welder the certification card.

An AWS “certification” is transferable, meaning any employer must recognize it.

Qualification

This simply refers to a welder testing to the requirements set forth in an applicable code. For most U.S. applications, this would be an AWS code book. The steps to gain “qualification” are a little simpler than certification.

Basically, one must insure the welding, inspection, and mechanical testing are conducted in accordance with the respective code. This does not necessarily require a CWI, but an independent CWI is generally contracted to assist. One reason is to remove any conflict of interest within the organization conducting the testing. The other reason is to insure the person “qualifying” the work has passed the testing requirements set forth by the AWS to properly interpret the code.

A welder qualification is governed and maintained by the manufacturing facility and may or may not be recognized by another employer.
AlcoTec School of Aluminum Welding Technology Course Outline

Classroom

Introduction to Aluminum Welding
- Historical perspective
- Industry information

The MIG (GMAW) Welding Process
- Transfer modes
- Welding power sources
- Shielding gases
- Wire feedability

The TIG (GTAW) Welding Process
- Current types
- Applications
- Procedures

Metal Preparation for Welding
- Storage and handling
- Cutting, beveling, and gouging
- Cleaning techniques
- Moisture control

Welding Procedures
- Joint design
- Machine settings
- Weld profiles

Alloy and Temper Designation System
- Alloysing elements
- Wrought alloys
- Cast alloys
- Temper designations

Welding Metallurgy
- Heat-treatable and non-heat-treatable alloys
- Weld metal composition
- Physical properties

Quality Control
- Code and standard requirements
- Welder and welding qualification procedures
- Acceptance criteria
- Testing methods
- Defect measurement

Design for Welding
- Applications
- Mechanical properties
- Design considerations
- Distortion control
- Life cycle monetization

Laboratory

Equipment Evaluation
- Drive roll geometry
- Liners and guides
- Contact tips
- MIG and TIG set up

Welding Test Samples
- Beveling and pre-cleaning
- Welding with MIG and TIG processes

Welding Inspection and Testing
- Visual inspection
- Fillet weld fracture tests
- Macros
- Bend tests
- Dye penetrant testing
- X-Ray evaluation

Test Results and Code Requirements
- Undercut, overlap, and weld profile evaluation
- Fusion and penetration limits
- Porosity limits

Visit alcotec.com/weldschool for more information.

Your aluminum partner.

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