Aluminum Weld Discontinuities: Causes & Cures
Kyle Williams
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Topics

- Definition of Terms
- NDE Methods for Aluminum Welds
- Cracks
- Incomplete - Joint Penetration / Fusion
- Porosity
- Weld Inclusions
- Weld Profiles
- Procedure Qualification Problems
- Summary
Terminology

Discontinuity
An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.

Defect
A discontinuity that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications.

Ref: ANSI/AWS A3.0-10 – Standard Welding Terms and Definitions
Nondestructive Test Methods for Aluminum Welds

Common:
- Visual (VT)
- Penetrant (PT)
- Radiographic (RT)
- Ultrasonic (UT)

Specialized:
- Eddy Current (ET)

Magnetic Particle (MT) cannot be used on aluminum.
Visual Inspection

Post-Weld Inspection
- General appearance
- Does it meet requirements

Pre-Weld Inspection:
- Improper materials or condition
- Joint fit-up

During Welding;
- Verify requirements of weld procedure
Liquid Penetrant Inspection

Used for detection of discontinuities that are open to surface

Two Common Methods:

- Visible Dye
- Fluorescent Dye
Radiographic Inspection

Used for detection of surface and internal discontinuities

Ultrasonic Inspection

Used for detection of surface and internal discontinuities

Basic Discontinuity Causes

- Improper metal preparation
  - Joint preparation
  - Cleaning
- Incorrect filler selection
  - Alloy or size
- Incorrect welding equipment
- Poor welding procedure or technique
Types of Discontinuities

- Cracking
  - Crater and weld
- Incomplete penetration
- Incomplete fusion
- Porosity
- Inclusions
  - Tungsten, copper and ferrous
## Inspection Methods

<table>
<thead>
<tr>
<th>Condition</th>
<th>Visual</th>
<th>Radiographic</th>
<th>Ultrasonic</th>
<th>Penetrant</th>
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<tbody>
<tr>
<td>Cracks</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Incomplete Joint Penetration</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Incomplete Fusion</td>
<td>X</td>
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<tr>
<td>Porosity</td>
<td>X</td>
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</tr>
<tr>
<td>Inclusions</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Crater Cracks

- Molten aluminum shrinks about 6% in volume as it solidifies, 2x that of steel
- Cracks will propagate in service
Crater Crack Prevention

- **“Button-Up” termination**
  - Start and stop the weld a couple times to add filler to compensate for crater shrinkage

- **“Crater-Fill” termination**
  - Taper down current using a crater fill function in the welding power supply or rapidly speed up traverse

- Stop on a run-out tab
Cold cracks

- Cause:
  - Insufficient weld strength under restraint
  - Shallow root pass

- Corrective means:
  - Increase root pass throat
  - Redesign to minimize restraint
  - Change welding sequence to minimize restraint
Weld Cracking

Hot cracks

Cause:
- Tensile stress on partially solidified weld or base metal
  - Incorrect filler alloy
  - Improper joint design
  - Excessive base alloy dilution
  - Low thermal gradient
Cracking from Incorrect Filler Alloy

Alloy 2014 welded with 4043 filler: Note cracking at fusion zone
Cracking from Incorrect Filler Alloy

![Temperature Chart]

- 1180°F (638°C)
- 1170°F (643°C)
- 1100°F (593°C)
- 1065°F (574°C)
- 1085°F (585°C)
- 1010°F (543°C)
- 1010°F (521°C)
- 2014°F (1100°C)
- 950°F (510°C)
- 4043°F (2229°C)
- 2319°F (1270°C)
- 4145°F (2280°C)

Diagram shows the critical temperature ranges for cracking in filler alloys.
Relative crack sensitivity vs. weld composition for various binary aluminum systems.
Dilution Ratios of Weld Joints

- **Fillet Welds**: 80% filler metal, 20% base metal
- **Single Vee-Groove Weld**: 60% filler metal, 40% base metal
- **Square Groove Weld**: 20% filler metal, 80% base metal
Weld Cracking

Hot cracks

- **Corrections:**
  - Proper joint design and filler
  - Compressive joint loading
  - Increased thermal gradient
    - Reduced interpass temperature
    - Chill bars
    - Increased travel speed
Incomplete Joint Penetration

Causes

- Insufficient welding current
- Excessive travel speed
- Inadequate joint preparation
- Inadequate back gouge
- Excessive arc length

Incomplete Joint Penetration – A joint root condition in a groove weld in which weld metal does not extend through the joint thickness

Ref: ANSI/AWS A3.0-10 – Standard Welding Terms and Definitions
Groove Weld Root Penetration

Incomplete Joint Penetration
Incomplete Fusion

Causes

- Inadequate oxide removal
- Insufficient heat input
- Narrow joint preparation
- Improper torch angle
- Excessive arc length
- Excessive travel speed
- Inadequate gas shielding
- Improper welding equipment

Incomplete Fusion – A weld discontinuity in which fusion did not occur between the weld metal and the fusion faces or the adjoining weld beads
Ref: ANSI/AWS A3.0-10 – Standard Welding Terms and Definitions
Incomplete Fusion Between Weld Passes
Aluminum Oxide

Cleaning Action
Arc Bombardment

Aluminum melts at
≈ 650°C (1200°F)

Weld

Aluminum Oxide melts at
≈ 2035°C (3700°F)
Root Side Oxide Displacement

Tight Integral or Removable Backing Support Before Welding

Lack-of-fusion in Root of Weld Due to Restricted Movement of the Oxide

Satisfactory Weld with Adequate Free Fall or Groove Depth in Backing
GMA Welding Power Supply Characteristics

Basic cause – Hydrogen

Hydrogen sources:
- Hydrocarbons
- Moisture
Weld Porosity: Hydrogen Solubility

Hydrogen Solubility (cm$^3$/100g) vs Temperature (°C)

- Solid
- Liquid

Temperature (°F) and Temperature (°C) with corresponding hydrogen solubility values:

- 660°C (1220°F): Hydrogen solubility = 0.69 cm$^3$/100g

T melting (1220°F): 660°C
Major Sources of Moisture or Hydrocarbons

**Base Metal**
- Residual lubricant
- Surface condensation
- Water stain
- Joint contaminants

**Filler Metal**
- Residual lubricant
- Hydrated oxide
- Improper storage

**Equipment**
- Water leaks
- Contaminated tools
- Improper grinding wheels

**Shielding Gas**
- Moisture contamination
- Turbulent shielding
Effect of Porosity on Mechanical Properties – 6061

Effect of Porosity on Mechanical Properties – 5083

Weld Inclusions – Tungsten

Causes

- Excessive current
  - Size
  - Tungsten type
- Aluminum contamination
  - Dip in weld
  - Touch with filler
- “Cold” starts
  - Heat on tab
  - Slope up current
Weld Inclusions – Tungsten

- Does not alloy with aluminum
- Treat as voids in weld

Radiograph of GTA Weld Showing Tungsten Inclusions
Weld Inclusions – Copper
Weld Inclusions – Copper

Causes

- GMAW contact tube “burn-backs”
- Improper GMA equipment set up
  - Drive rolls, inlet/outlet guides, contact tip and liner
  - Waves, kinks, snags in electrode
- Copper backing – melting at open joint
Causal Factors for Weld Inclusions – Ferrous:

- Wire brush bristles in joint
- Steel backing or fixture
  - Melting at open joint
  - Rust flakes in joint
Weld Inclusions – Copper and Ferrous

- Alloy with aluminum
- Forms brittle interface
- Surface corrosion hazard

Copper and ferrous inclusions are unacceptable to most aluminum welding codes and standards and require removal.
Weld Profiles

Undercut
- Excessive welding currents
- Improper welding technique

Overlap
- Improper welding current / technique
- Oxide on surface of base metal
Weld Profiles

Convexity / Concavity

- Reduced mechanical properties and fatigue strength
- Improper arc length
- Improper welding technique
Common Procedure Qualification Problems

- **Tensile tests**
  - Using too small of a test specimen

- **Guided bend testing**
  - Plunger type equipment used only for soft or annealed tempers
  - Wrap-around best for all aluminum alloys
  - Improper bend radius or specimen thickness
Guided Bend – Plunger

Improper
The bend is too sharp.
Common fault with plunger-test for hard alloy tempers.

Proper
Correct bend.
Suitable only for soft alloys and annealed temper.

(Use wrap-around test to avoid bending faults.)
Guided Bend – Wraparound
## Guided Bend – Wraparound Requirements

<table>
<thead>
<tr>
<th>Spec. Thick (in.)</th>
<th>A Diameter (in.)</th>
<th>B Radius (in.)</th>
<th>Materials</th>
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<tbody>
<tr>
<td>3/8 t</td>
<td>1 - 1/2</td>
<td>3/4</td>
<td>M-21 1060, 1100, 3003, Alclad 3003, 5005, 5050</td>
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<td>2/t</td>
<td>M-22 3004, Alclad 3004, 5052, 5154, 5254, 5454, 5652</td>
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<td>1/8 T (&lt;1/8)</td>
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<td>F-23 All Welds with 4010, 4043, 4047, 4145 &amp; 4643 Filler Alloys</td>
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<td>6 - 2/3t</td>
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<td>M-25 5083, 5086 &amp; 5456</td>
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<tr>
<td></td>
<td>8t</td>
<td>4t</td>
<td>M-27* 7005</td>
</tr>
</tbody>
</table>

*Shall be tested within two weeks of welding

Note: M26 Cast Base Alloys Are Not Bend Tested

Ref: AWS D1.2: 2008 Structural Welding Code – Aluminum, Figure 3.13
Quality aluminum weldments can be made by:

- Use of proper welding procedures
- Use of proper welding equipment
- Reasonable production control of material cleanliness and joint fit-up

The best quality control is a properly trained conscientious welder.
Advancing each generation.