Autogenous Laser Welding of Aluminum

Hans Leidich
OEM Laser Specialist
Laser Technology Center
TRUMPF Inc.
Why Autogenous

- Simpler
  - Less hardware
  - Easier process
  - Faster speed
- Should be first approach (if doesn’t work, then go to the next step)
Autogenous Welding

- Material
- Joint Design/Issues
- Process
Material Selection

Notes for welding aluminum

- Critical issues – HAZ softening, blow holes, porosity, solidification cracking & in some alloys - loss of volatile elements (e.g. Mg, Zn) due to vaporization
- Natural oxides on surface + moisture from atmosphere produce hydrogen which is highly soluble in Al & causes porosity
- Anodized aluminum prone to cracking & foams up
- Remove Al oxide (AlO₂ @ \( T_{\text{melt}} = 1800°C \) compared to \( 700 °C \) for Al) for overlap joints to increase weld width at interface
- 1000 series: (e.g. 1050=Al 99.5) welds good. Also 3003, 4032, 4047 okay.
- 5000 series: (e.g. 5005, AlMg5) most weld good. Filler wire if needed: AlMg5 or AlMg4.5Mn (e.g. AlMg3 + AlMg5 wire = poor appearance w/ good strength)
- 6000 series: (e.g. AlMgSi1 – silicon added for machinability) – not ductile enough to handle shrinkage stresses & is prone to cracking. Weldable when Si>3% & Mg>4.5% (e.g. 6061). Filler wire used to increase weldability (e.g. AlMgSi1 + AlSi12 wire = good appearance w/ average strength)
- Shield gas = generally Argon, Helium to avoid inclusions and sink holes

Autogenous Laser Welding of Aluminum

TUSD281hl
Crack Susceptibility

Relative Crack Susceptibility

- Base metal with matching or no filler
- Base metal with different filler metals

Limit of Weldability
Easy to Weld

Welding Journal, January 2000 - used with permission
### Wrought alloy series designations

<table>
<thead>
<tr>
<th>Alloy Series</th>
<th>Principal alloying element</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1xxx</td>
<td>Aluminum (&gt;99%)</td>
<td>Fusion weldable</td>
</tr>
<tr>
<td>2xxx</td>
<td>Copper</td>
<td>Fusion weldable w/ filler wire (prone to hot cracking except 2014, 2219 &amp; 2519)</td>
</tr>
<tr>
<td>3xxx</td>
<td>Manganese</td>
<td>Fusion weldable, most common 3003 &amp; 3103 w/o filler wire</td>
</tr>
<tr>
<td>4xxx</td>
<td>Silicon</td>
<td>Fusion weldable</td>
</tr>
<tr>
<td>5xxx</td>
<td>Magnesium</td>
<td>Fusion weldable (crack sensitivity in low Mg alloys (1-3%) – AlMg filler wire)</td>
</tr>
<tr>
<td>6xxx</td>
<td>Magnesium &amp; Silicon</td>
<td>Fusion weldable w/ AlSi filler wire (prone to hot cracking)</td>
</tr>
<tr>
<td>7xxx</td>
<td>Zinc</td>
<td>Few alloys fusion weldable (prone to porosity, blow holes &amp; hot cracking)</td>
</tr>
<tr>
<td>8xxx</td>
<td>Lithium</td>
<td>Some alloys fusion weldable, filler wire used to optimize weldability &amp; mechanical properties (prone to porosity &amp; blow holes)</td>
</tr>
</tbody>
</table>

**Notes**

1. **XXXX** alloys heat treatable (age hardenable) / **XXXX** alloys are strain hardenable
2. Wrought alloys available in sheet, plate, extrusions, forgings, rod, bar and impact extrusions
## Specific welding recommendations

<table>
<thead>
<tr>
<th>Alloy Series</th>
<th>Welding depth free of blow outs (mm)</th>
<th>Filler wire</th>
<th>Shielding gas [4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1xxx</td>
<td>&gt; 1</td>
<td>Not necessary</td>
<td>Not necessary, but better surface w/ He or He/Ar mix</td>
</tr>
</tbody>
</table>
| 5xxx [3]      | 3                                    | 4047 – good surface  
5356 – poor appearance, good strength | He or He/Ar mix |
| 6xxx [2][3]   | 4                                    | 4047 – good appearance, ave. strength  
4043 – better seam elevation | Not necessary, but better surface w/ He or He/Ar mix |
| Casting alloys| > 2.5                                | Crack free without wire  
Fewer blowouts with 4047 | Not necessary, but better surface w/ He or He/Ar mix |

### Notes

1. Anodized aluminum prone to cracking and foams up
2. **XXXX** alloys heat treatable
3. Twin spot optics w/ 3 kW min. for 1 μm & 6 kW min. for 10.6 μm power can be used to increase process stability, decrease blowouts & increase weld pool homogenization, but decreases speed 20-30% compared to single focused spot
4. Helium is best (but most expensive) for avoiding inclusions, sink holes and for greater process stability. Argon generally recommended, but has a higher susceptibility to porosity. He/Ar mixes are generally 70/30. Nitrogen can be used to reduce porosity but results in a rougher weld bead surface. CO₂ has been successfully used on 6xxx series aluminum but has negative effects on others series aluminums.
Seam and joint types

- **Lap Weld**
- **Butt Weld**

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<table>
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<th>Example</th>
<th>Characteristics</th>
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</table>
| Butt Weld   | ![Diagram](butt_weld.png) | + **Weld Fusion Area**  
  - less material = weight & cost savings  
  - faster or less power  
  - less HAZ / distortion  
  
  - **Positioning Tolerance**  
  - edge requirements  
  - fit up can be more difficult to obtain |
| Lap Weld    | ![Diagram](lap_weld.png)   | + **Positioning Tolerance**  
  - larger process window  
  - can have aesthetic underside  

  - **Weld Fusion Area**  
  - more energy required = slower or higher power & more distortion / HAZ  
  - inefficient process |
## Seam and joint types

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| Butt Weld on stepped lap joint| ![Example](image) | + weld fusion area  
- positioning tolerance |
| Seam weld on T-joint          | ![Example](image) | + weld fusion area  
- positioning tolerance |
<table>
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<tr>
<th>Name</th>
<th>Example</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Lap weld on T / border joint     | ![Image](lap焊) | + positioning tolerance  
- weld fusion area |
| Seam weld on flange              | ![Image](seam焊)  | + weld fusion area  
- positioning tolerance |
| Lap weld on formed seam          | ![Image](lap焊)  | + positioning tolerance  
- weld fusion area |
Lap Weld – No Fusion
Cracking
Cracking – Centerline
Cracking – 90 Deg. Bend
Fillet Weld - Cracking

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Shielding Gases

- Argon
  - Heaviest weight
  - Low cost

- Helium
  - Lightest weight
  - 3x cost of Ar

- Nitrogen
  - “Neutral” weight
  - ½ cost of Ar

- Air
  - “Neutral” weight
  - “Free”
Shield Gas – Cross Section

- Argon: 2.04 mm, 1.59 mm
- Helium: 1.08 mm, 1.44 mm
- Nitrogen: 1.65 mm, 1.47 mm
- No Gas: 1.83 mm, 1.45 mm

Autogenous Laser Welding of Aluminum  TUSD281hl
Shield Gas – Top View

- **Argon**
- **Helium**
- **Nitrogen**
- **No Gas**
Porosity and blow holes

- Trapped gases due to:
  - volatile alloying constituents (e.g. Zn, Mg, Li)
  - hydrogen outgassing
  - keyhole instability

- Solutions:
  - Create path & time for vapors to exhaust
    \[ \Rightarrow \text{Reduce speed, twin spot} \]
**Twin Spot**

Conventional laser welding:
Expulsion of molten material

TWISTLAS ® Technology:
Improved Key Hole Stability
**Beamforming with bifocal and Twistlas**

**Principle:** Welding with two focused laser beams generated by one or two lasers

**Objective:**
- Increased weld quality and process stability in aluminum welding
- Higher positioning and gap tolerance in butt joints

**Twistlas**
- Fiber optic cable
- Collimating lens
- Wedge
- Focusing lens

**Bifocal**
- Power-Addition
- Power-Distribution
Welding with TWISTLAS®: 4 kW & 3 kW SSL

Material: Al99.5
Power: 4 kW+3 kW
Optic: f=150mm
Focus diameter: 0.45 mm
Focus distance: 0.54 mm

Tandem arrangement
Parallel arrangement

Fiber ends TWIN-LLK
Parameters influencing seam quality

- thickness
- alloy
- filler wire
- welding speed
- shielding gas
- seam preparation
- focal diameter
- welding position
- laser power
- focal position
Best practice for successful autogenous aluminum welding:

- Avoid “problematic” material
- Good joint fit-up (minimal gap)
- Convex bead shape
- Minimize start/stops (crack initiation points)
Thank you for your attention!