Joining Aluminum and Other Materials

The Aluminum Transportation Group
Tamer O. Girgis, Ph.D.
Aleris
Surface Treatment R&D/Sr. Applications Engineering
Joining Outline

• Objective
• Material property, difference between aluminum alloys and steels
• Material property testing and key parameters
• Joining processes evaluation
• Joining processes and its automotive applications
• Joining challenges and its remedies
• Quality measures in joining processes
Importance of Joining of Aluminum and its Alloys

- Low relative density (~ 2.7)
- Reasonably high tensile strength and ductility
- High strength to weight ratio
- Excellent electrical and thermal conductivity
- Corrosion resistance
- Easy fabrication
Properties of Aluminum Alloys

- Melting point < 660°C
- Working temperature < 250°C
- Strengthening mechanisms:
  - Precipitation hardening: forming of coherent precipitates in Al-Cu alloys on aging after quenching
  - Solid solution strengthening: substitutional solid solutions impede motion of dislocations
  - Dispersion strengthening: dispersion of hard second phase particles in the matrix
  - Cold working
- High coefficient of thermal expansion (2x that of steel)
- High thermal conductivity
- High oxidizing potential
Joining Processes Overview

Joining processes and equipment

The weld joint, quality, and testing

Safety and environmental considerations

Welding

Adhesive bonding

Mechanical fastening

Fusion

Brazing and soldering

Solid state

Chemical

Electrical

Chemical

Mechanical

Oxyfuel gas
Thermit

Arc
Resistance
Electron beam
Laser beam

Electrical

Resistance

Diffusion
Explosion

Cold
Friction
Ultrasonic

Fastening
Seaming
Crimping
Stitching
## Current Joining Options for High-Volume Auto Sheet Components

<table>
<thead>
<tr>
<th>Joining Method</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance Spot Welding</td>
<td>• Reliability &amp; consistency w/ Al</td>
</tr>
<tr>
<td>Self-Piercing Rivets</td>
<td>• Inspection method</td>
</tr>
<tr>
<td>Flow-Drill Screws</td>
<td>• Common infrastructure &amp; capital</td>
</tr>
<tr>
<td>Adhesive Bonding</td>
<td>• Cannot join dissimilar materials</td>
</tr>
<tr>
<td></td>
<td>• Specific rivet &amp; tooling for each stack-up/material combination</td>
</tr>
<tr>
<td></td>
<td>• High deformation limits materials to be joined</td>
</tr>
<tr>
<td></td>
<td>• Speed of installation</td>
</tr>
<tr>
<td></td>
<td>• Weight &amp; cost</td>
</tr>
<tr>
<td></td>
<td>• Backside protrusion</td>
</tr>
<tr>
<td></td>
<td>• Durability</td>
</tr>
<tr>
<td></td>
<td>• Curing conditions</td>
</tr>
<tr>
<td></td>
<td>• Always in combination with spot-based joining</td>
</tr>
</tbody>
</table>
Automotive RSW Lines – Flexibility is King

- Multiple automotive models flow down single respot lines. Each gun dynamically changes its weld schedule to accommodate the multiple stackups for each individual assembly

Example – Two different auto assemblies run down the same respot line

RSW process flexibility enables OEMs to make gauge or product changes without the downtime and capital costs to retool
Dissimilar Materials Joining Adds Further Cost & Complexity

- Aluminum requires OEMs to upgrade RSW and/or add new joining technologies
- Complexity of joining is magnified with multi-materials designs

2015 Ford F150
Aluminum Intensive BiW & Closures

- 12 different component materials
- 11 different joining methods
- ~5,000 joining elements

BiW Structure Material Properties of the new Generation S-Class

- 53 different component materials
- 17 different joining methods
- ~8,000 joining elements
Metal Joining Process Overview

What is metal joining process?
• Joining of two metal parts either temporarily or permanently with or without application of heat or pressure.

Classification:
• Bolting: temporary joining
• Riveting: permanent joining
• Welding/brazing/soldering: permanent joining
Welding Processes

- **Fusion Welding**: Coalescence is accomplished by melting the two components to be joined, in some cases adding filler metal to the joint.
  - Examples: Arc welding, resistance spot welding (RSW), oxyfuel gas welding

- **Solid State Welding**: Heat and/or pressure are used to achieve coalescence, but no melting of base metals occurs and no filler metal is added.
  - Examples: Friction welding, forge welding, diffusion welding
Aluminum Alloys Weldability

Definition: The resistance of the weld metal to solidification cracking and porosity.

- Effect of the welding process:
  - Heat effects (HAZ)
  - Dilution percentage
- Effect of nature of base metals prior to welding:
  - Surface condition
  - Chemistry
  - Mechanical properties
- Effect of alloying elements:
  - Hydrogen induced cracking (HIC)
Classification of Welding Processes

Welding Processes

Positive-Pressure Gas Processes
- Air-Acetylene
- Oxy-Acetylene
- Oxy-Hydrogen
- Pressure gas

Welding Processes

Arc Welding
- Carbon Arc
  - SMAW
  - SAW
  - GTAW
  - MIG
  - Electroslag
  - Plasma Arc
- Seam
- Spot

Resistance Welding
- Cold
  - Explosive
  - Friction
- Roll
- Diffusion
- Forge
- Hot Pressure
- Ultrasonic Welding

Solid State Welding
- Thermit Welding
  - Atomic Hydrogen Welding
- Electron Beam Welding
  - Laser Beam Welding

Thermo-Chemical Welding
Classification of Welding Processes
Resistance Welding (RW)

A group of fusion welding processes that uses a combination of heat and pressure to accomplish coalescence.

- Heat generated by electrical resistance to current flow at junction to be welded
- Resistance spot welding (RSW) is the main process in the RW group

**Advantages:**
- High production rates
- No filler metal required
- Good repeatability and reliability

**Limitations:**
- Limited to lap joints
Resistance Spot Welding (RSW)

- Components inserted between electrodes
- Electrodes close; force applied
- Current ON
- Current OFF
- Electrodes open

Resistance Spot Welding Cycle

Force and Current Plot
Resistance Spot Welding Equipment

Robotic Spot Welding System
Source: Kuka Systems

Servo-controlled Spot Welding Gun
Source: ARO
## Minimum Spot Weld Size and Spacing

<table>
<thead>
<tr>
<th>Metal Thickness (mm)</th>
<th>0.65</th>
<th>0.81</th>
<th>1.02</th>
<th>1.27</th>
<th>1.60</th>
<th>1.80</th>
<th>2.03</th>
<th>2.29</th>
<th>2.54</th>
<th>3.18</th>
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</thead>
<tbody>
<tr>
<td><strong>Minimum Weld Button Diameter (mm)</strong></td>
<td>$4\sqrt{t}$</td>
<td>3.1</td>
<td>3.6</td>
<td>4.1</td>
<td>4.6</td>
<td>5.1</td>
<td>5.3</td>
<td>5.7</td>
<td>6.1</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>Recommended Weld Button Diameter (mm)</strong></td>
<td>$5\sqrt{t}$</td>
<td>3.8</td>
<td>4.3</td>
<td>4.8</td>
<td>5.3</td>
<td>6.1</td>
<td>6.6</td>
<td>6.9</td>
<td>7.2</td>
<td>7.6</td>
</tr>
<tr>
<td><strong>Minimum Weld Spacing (mm)</strong></td>
<td>9.5</td>
<td>12.7</td>
<td>15.9</td>
<td>19.0</td>
<td>22.2</td>
<td>25.1</td>
<td>31.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Minimum Edge Distance (mm)</strong></td>
<td>5.6</td>
<td>6.4</td>
<td>7.9</td>
<td>9.5</td>
<td>11.1</td>
<td>12.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Minimum Overlap (mm)</strong></td>
<td>11.1</td>
<td>12.7</td>
<td>14.3</td>
<td>15.9</td>
<td>19.0</td>
<td>20.6</td>
<td>22.2</td>
<td>23.8</td>
<td>25.1</td>
<td>28.6</td>
</tr>
</tbody>
</table>

Ref: AA Welding Aluminum, Table 13.1
Tensile Shear Strength Performance of AL Resistance Spot Welds

- Typical strength of automotive Al spot welds fall within the middle alloy ranges (150 to 300 MPa)
- Investigating RSW performance of ultra-high strength alloys (>386 MPa) in combinations with similar or lower Al grades
- New robotic RSW cell has process capabilities to effectively weld the ultra-high strength grades

![Graph showing tensile shear strength performance](image-url)
Resistance Seam Welding (RSEW)

- Uses rotating wheel electrodes to produce a series of overlapping spot welds along lap joint
- Can produce air-tight joints
- Applications:
  - Gasoline tanks
  - Automobile mufflers
  - Various other sheet metal containers
Joint Configurations Suitable for Resistance Spot Welding

- Two or more components are overlapped in the region to be joined
- Along a weld flange specifically incorporated on the components for the purpose of accommodating the spot welds
Resistance Spot Welding Cross Section Evaluations

- Ideal aluminum spot weld cross section
- Good nugget shape
- Good penetration
- No cracks
- Minimal porosity

Non-conformities of resistance spot welds are:
- Cold welds
- Too small nuggets
- Cracks, porosity, pores, etc. inside the welding nugget
# Typical Aluminum Spot Welding Parameters

<table>
<thead>
<tr>
<th>Metal Thickness (mm)</th>
<th>0.80</th>
<th>0.80</th>
<th>1.00</th>
<th>1.30</th>
<th>1.60</th>
<th>1.80</th>
<th>2.00</th>
<th>2.30</th>
<th>2.50</th>
<th>3.20</th>
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<tbody>
<tr>
<td><strong>Radius (mm)</strong></td>
<td>Radiused</td>
<td>50.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>152.4</td>
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<tr>
<td></td>
<td>Truncated</td>
<td>76.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Electrode Diameter (mm)</strong></td>
<td>15.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22.2</td>
</tr>
<tr>
<td><strong>Electrode Face Diameter (mm)</strong></td>
<td>6.4</td>
<td>7.8</td>
<td>9.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.0</td>
</tr>
<tr>
<td><strong>Angle (Degree)</strong></td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45</td>
</tr>
<tr>
<td><strong>Weld Force kN (lbs)</strong></td>
<td>Radiused</td>
<td>3.6 (800)</td>
<td>4.0 (900)</td>
<td>4.5 (1000)</td>
<td>5.3 (1200)</td>
<td>6.2 (1400)</td>
<td>7.1 (1600)</td>
<td>8.0 (1800)</td>
<td>10.7 (2400)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truncated</td>
<td>2.2 (500)</td>
<td>2.5 (550)</td>
<td>2.7 (600)</td>
<td>3.1 (700)</td>
<td>3.8 (850)</td>
<td>4.1 (920)</td>
<td>4.6 (1040)</td>
<td>5.1 (1150)</td>
<td>5.8 (1250)</td>
</tr>
<tr>
<td><strong>Weld Time</strong></td>
<td>Number of 60Hz Cycles</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>DC Welding Current kA RMS</strong></td>
<td>As Received Surface</td>
<td>20</td>
<td>22</td>
<td>23</td>
<td>25</td>
<td>30</td>
<td>32</td>
<td>35</td>
<td>37</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Mechanical and/or Chemically Cleaned Surface</td>
<td>21</td>
<td>24</td>
<td>25</td>
<td>27</td>
<td>31</td>
<td>33</td>
<td>36</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td><strong>AC Welding Current kA RMS</strong></td>
<td>As Received Surface</td>
<td>22</td>
<td>27</td>
<td>28</td>
<td>30</td>
<td>33</td>
<td>36</td>
<td>39</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Mechanical and/or Chemically Cleaned Surface</td>
<td>24</td>
<td>29</td>
<td>30</td>
<td>33</td>
<td>37</td>
<td>39</td>
<td>42</td>
<td>46</td>
<td>48</td>
</tr>
</tbody>
</table>
Friction Stir Welding

Advantages:
- Good mechanical properties
- Narrow heat affected zone (HAZ)
- No fusion zone
- No filler alloy addition or shielding gas
- Joining dissimilar metals and non-fusion weldable aluminum alloys (e.g. 7050 & 7075)
- Excellent weld quality with no porosity that can arise in fusion welding process
- Environmentally friendly no fumes or spatter are generated; no arc glare or reflected laser beams to contend

Challenges:
- Requires good fit-up and clamping systems
Mechanical Joining Technologies of Aluminum

Four methods most often under consideration:

• Adhesives
• Self-pierce rivets (SPR)
• Clinching
• Flow drill screws (FDS)
Adhesive Bonding

A variety of adhesives exists for very specific applications and requirements

Advantages:
• Joining mixed material applications with dramatically different melting points.
• Sealing and insulating dissimilar substrates which would cause corrosion using other joining methods.

Challenges:
• Surface preparation requirements

Property Range of Adhesives (Source: Henkel)
Self-Piercing Rivets

Advantages:

- High-strength joints that are suitable for visual inspection.
- Reproducible and requires no pre-drilling.
- Joints are watertight and airtight.
- Joining both metallic and non-metallic materials and will fasten dissimilar metals.
- Suitable for use with different material strengths and thicknesses.
- Meeting requirements from manual assembly right up to the most automated processes.

Note: For best joint integrity, the self-pierce rivet should be inserted from the thin material into the thick, and from the hard into the soft.

(Jaguar’s F-Type has an aluminum body assembled by self-piercing rivets)

(Source: Henrob)
Self-Piercing Rivets

Rivet Cross-Sections

5754-0 Rivet
w/o Adhesive

6013-T6 Rivet
w/o Adhesive
Self-Piercing Rivets

**SPR Lap Shear Data**

Joint Strength (Kn)

<table>
<thead>
<tr>
<th>Material</th>
<th>No Adhesive</th>
<th>With Adhesive</th>
</tr>
</thead>
<tbody>
<tr>
<td>5754-0</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>6013-T4</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>6013-T6</td>
<td>9</td>
<td>22</td>
</tr>
<tr>
<td>6022-T4</td>
<td>8</td>
<td>18</td>
</tr>
</tbody>
</table>

2 mm material (both samples joined were same alloy)
Clinching/Clinch Rivet

- Clinching is a common joining technology that does not require consumables or pre-drilled holes.
- It is performed in a single step where stacked, ductile materials are pressed into a die with a punch.
- Clinch rivet uses a combined drawing and pressing action to produce an effective joint from a simple cylindrical rivet.
- The punch forces the materials down and radially out into the die which creates a strong mechanical bond.
- This process does not provide corrosion resistance.
1. Flow Drilling Screw (FDS) is applied to the material surface with medium thrust and spindle rotation.

2. As friction and heat increases, the substrate surface plasticizes and begins to “flow.”

3. Material begins to form the extended threading behind the application.

4. As the flow phase ends the “thread rolling” phase begins with lower RPM on the spindle.

5. The screw acts like a normal fastener and is driven to a torque.

6. The fastener is seated via normal torque strategy. As the materials cool, it contracts around the threads for added joint integrity.
EJOT® Flow Drill Screw

Installation Process:

![Image of Installation Process]

![Graph showing RPM and Torque](image-url)
EJOT® Flow Drill Screws

Lap Shear Joint with Pilot Hole

Lap Shear Joint w/o Pilot Hole
EJOT® Flow Drill Screws with 40mm Overlap

EJOT Average Lap Shear Data

<table>
<thead>
<tr>
<th>Alloy</th>
<th>w/o Adhesive_No Pilot</th>
<th>w/o Adhesive_7mm Pilot</th>
<th>w/Adhesive_No Pilot</th>
<th>w/Adhesive_7mm Pilot</th>
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<tbody>
<tr>
<td>5754-0</td>
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<tr>
<td>6013-T4</td>
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<td>6022-T4</td>
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<tr>
<td>7075-T6</td>
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</tr>
</tbody>
</table>

Joint Strength (kN)
Friction Welding

- Friction heat caused by the motion of one surface against another enables plastic deformation and atomic diffusion at the interface.
- The weld is formed across the entire cross-sectional area of the interface in a single shot process.
Friction Welding

- Rotating part, no contact
- Parts brought into contact to generate friction heat
- Rotation stopped and axial pressure applied
- Weld created
Friction Welding – Advantages and Limitations

Advantages:
• Low heat distortion
• Good joint properties (low heat-affected zone)
• Weld through lubricants
• Surface preparation not critical
• Excellent joint properties
• Low energy joining process
• Environmentally friendly no arcs and fume emissions
• Joining dissimilar metals
• No water cooling or filler materials required

Limitations:
• Requires good workpiece alignment
• Flash usually need to be removed (extra operation)

Applications:
• Automotive drive shafts
• Suspension components
• Axles
# Common Joining Technologies for Different Material Combinations

<table>
<thead>
<tr>
<th>Joining Technology/Material Combination</th>
<th>Al – Al</th>
<th>Al – Steel</th>
<th>Al – Mg</th>
<th>Al – Composite</th>
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<tbody>
<tr>
<td>Resistance Spot Welding</td>
<td>★</td>
<td></td>
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<tr>
<td>Friction Stir Spot Welding</td>
<td>★</td>
<td>★</td>
<td></td>
<td></td>
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<tr>
<td>Laser Welding/Laser Brazing</td>
<td>★</td>
<td>★</td>
<td></td>
<td></td>
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<tr>
<td>Fasteners (SPR, FDS, Nails)</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
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<tr>
<td>Clinching</td>
<td>★</td>
<td>★</td>
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<td>★</td>
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<tr>
<td>Adhesive Bonding</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
</tr>
</tbody>
</table>

Source: CAR 2017
Questions?
How to join

Web

Text

1

1

2

2
An ideal aluminum resistance spot weld will exhibit:

- Good nugget shape
- Good penetration
- No cracks
- Minimal porosity
- All of the above
Self-piercing rivets are stronger than clinching.
Riveting and welding are classified as a temporary joining processes.
In a flow drill screw joining Al 6xxx alloy application, having a pilot hole in conjunction with adhesives enhances the joint lap shear strength.
Tell Us How We Did!

1. Open a browser on your laptop, tablet or mobile device
2. Visit: pollev.com/aassociation001
3. Give us feedback!