Zhi Deng
• Aleris
• Global Sr. Applications Engineer
Forming Outline

1. Material property, difference between aluminum alloys and steels
2. Material property testing and key parameters
3. Formability and formability evaluation (FLC test, cup drawing test, hole expansion test, …)
4. Stamping press lines and applications
5. Typical forming modes and requirements on material property/formability
6. Formability issues in stamping processes (splits, edge cracking, …)
7. Quality issues in stamping processes (wrinkling, springback, surface quality, …)
8. Stamping process issues (die wear, galling, lubrication, …)
Portfolio of Body In White Applications

- High Formability
- Hemming
- Scrap absorbing
- Surface (Roping)
- High Strengths
- Crash
- EDT-Texture
  - Pre-treatment
    - Hot melt
    - Passivation
- Pedestrian safety
Sheet Metal Formability

Formability Evaluation - Based on stress/strain state

- **Drawability**
- **Stretchability**
- **Flangeability**
- **Bendability**

**Drawing dominated**

**Stretching dominated**

- $\sigma_1$
- $\sigma_2$
- $\sigma_3$
Sheet Metal Formability Assessment

Sheet Metal Formability Evaluation

Basic Material Property

• Yield
• Strength
• Tensile
• Strength

Simulative Material Formability

• Drawability
• Stretchability
• Bendability
• Flangeability
Sheet Metal Formability Assessment

1. Intrinsic Tests
   - Providing comprehensive data that are insensitive to material thickness and surface conditions

2. Simulative Tests
   - Providing limited and particular information that is sensitive to thickness, surface conditions, lubrication, and type/geometry of tooling

3. Basic Material Property

4. Sheet Metal Formability for a Specific Deformation or Formability Process
Basic Material Property Tests

- Uniaxial Tensile Test
- Hydraulic Bulge Test
- Shear Test
- Tensile-Compression Test
- Buckling Test
Tensile Test vs. Bulge Test

Uniaxial Anisotropy

\[ r = \frac{\varepsilon_w}{(\varepsilon_l + \varepsilon_w)} \]

Biaxial Anisotropy

\[ r_B = \frac{\varepsilon_T}{\varepsilon_R} \]

YS, TS, UL, TL, n, r
Hydraulic Bulge Test

International Standard
ISO 16808

Metallic materials — Sheet and strip — Determination of biaxial stress-strain curve by means of bulge test with optical measuring systems

Matériaux métalliques — Tôles et bandes — Détermination de la courbe contrainte-déformation biaxiale au moyen de l’essai de gonflement hydraulique avec systèmes de mesure optiques
Hydraulic Bulge Test

Stress and Strain Calculations

\[ \bar{\sigma}_{isotropic} = \frac{p}{2} \left( \frac{R_b}{t} + 1 \right) \]
\[ \bar{\varepsilon}_{isotropic} = \ln \frac{t_0}{t} \]
\[ \bar{\sigma}_{anisotropic} = \bar{\sigma}_{isotropic} \sqrt{2 - \frac{2r}{1+r}} \]
\[ \bar{\varepsilon}_{anisotropic} = \frac{2\bar{\varepsilon}_{isotropic}}{\sqrt{2 - \frac{2r}{1+r}}} \]
Forming Limit Diagram / Curve

A forming-limit diagram (FLD) is a diagram containing major/minor strain points.

An FLD can distinguish between safe points and necked or failed points. The transition from safe to failed points is defined by the forming-limit curve (FLC).

To determine the forming limit of materials, two different methods are possible.

1) Strain analysis on failed press shop components to determine component and process dependent FLCs:

In the press shop, the strain paths followed to reach these points are generally not known. Such an FLC depends on the material, the component and the chosen forming conditions. This method is described in ISO 12004-1.

2) Determination of FLCs under well-defined laboratory conditions:

For evaluating formability, one unique FLC for each material in several strain states is necessary. The determination of the FLC has to be specific and it is necessary to use different linear strain paths. This method should be used for material characterization as described in ISO 12004-2.
FLC Test

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FLC Measurement With DIC

Digital Image Correlation (DIC):
• an optical method that employs tracking and image registration techniques for accurate 2D/3D measurements of changes in images
• used to measure full-field displacement and strains
• well suited for the characterization of material properties in the elastic and plastic ranges
FLC Testing Methods

INTERNATIONAL STANDARD

ISO 12004-2

Metallic materials — Sheet and strip —
Determination of forming-limit curves —

Part 2:
Determination of forming-limit curves in
the laboratory

Dimensions in millimetres

105 ±5

R10

R 5

100 ±2

0.2D

0.1D

1.2D

ΦD_ch

0.1D

Φ100 ±25 (ID)
FLC Testing Methods

Marciniak Test
- More difficult in operation
- In-plane deformation
- No friction effect
- Linear strain path
- $FLC_0$ at plane strain axis

Nakazima Test
- More widely used
- Out of plane deformation
- Sensitive to friction condition
- Non-linear strain path
- $FLC_0$ shifts to the right

![FLC Diagram](image.png)
FLC Applications In Stamping Plant

Circle grid analysis

Argus measurement

Failure
Marginal
Safe

Less stretch
More mat flow

More stretch
Less mat flow
Sharpen features

Soften features

Less stretch
More mat flow
Soften features

Less stretch
More mat flow
Soften features

Major Strain, $\varepsilon_1$

Minor Strain, $\varepsilon_2$
Simulative Formability Tests

Specific testing to evaluate sheet metal

Drawability, Stretchability, Flangeability, Bendability

or Combined formability: mostly draw-stretch ability

Other specific testing to evaluate stamping feasibility

Tribology, Surface Quality and Paint Ability, ……
Simulative Formability Tests – Drawability

- Most extensively used test to evaluate sheet metal deep drawability
- Circular blanks with progressively larger diameters are clamped between die and blank holder and deep drawn into cups using a flat-bottomed [50.8 mm (2.0 in.) diameter] cylindrical punch
- Sheet metal experiences a large deformation in the flange and substantial sliding is involved at the die radius
Simulative Formability Tests – Drawability

Testing Parameter

Limiting Draw Ratio (LDR) = Max. Blank Diameter / Punch Diameter

- Blanks of different diameters are drawn until one splits.
- Enough binder force is applied to prevent flange wrinkling.
- Usually 6-10 blanks with blank diameter/punch diameter intervals of 1.0 mm give an acceptable value of LDR.
Simulative Formability Tests – Stretchability

- The Erichsen test uses a hardened steel ball of 20 mm in diameter, a die with a 27 mm internal diameter and a 0.75 mm die profile radius.
- The Olsen test uses a 22.2 mm diameter ball, a die with either a 25.4 mm or 28.6 mm (for thickness > 1.5 mm,) internal diameter and a 0.81 mm corner radius of the die and the blank holder.

![Erichsen/Olsen Test Setup](image-url)
Simulative Formability Tests – Stretchability

Testing Parameter

Erichsen / Olsen Index = Max. Dome Height (h) at Fracture (preferred max. load)

- A flat specimen is held tightly between the die and blank holder and deformation occurs in the small central area of the specimen.
- Since little drawing occurs during testing, results are often used to evaluate and compare sheet metal stretchability.
- Erichsen test is widely used in Europe and results are shown in SI units
- Olsen test is widely used in US and results are shown in US units.
Simulative Formability Tests – Stretchability

- Erichisen and Olsen tests show poor repeatability of results and correlation with other material properties or production conditions
- attributed to insufficient size of the punch and inability to prevent inadvertent draw in of the flange during testing
- LDH test is developed and more widely used

Testing Parameter

LDH Index = Max. Dome Height before Blank Cracking
- LDH test uses a much larger hemispherical punch
- Specimen is clamped with the lock bead in order to prevent flange draw in
- LDH test results correlate better with the total elongation than with the uniform elongation
Simulative Formability Tests – Flangeability

- Specimen with a circular hole in the center
- Clamped between die and blank holder and deformed by a punch
- Expanding and ultimately cracking the edge of the hole
- Flat-bottomed cylindrical and conical punches are mostly used
- Test is terminated when a visible edge crack or fractured hole diameter is noticed

Testing Parameter

\[ \text{Hole expansion ratio (\%)} = \frac{D_f - D_0}{D_0} \times 100 \]

\((D_0, D_f \text{ are the original and final hole diameters.})\)
Simulative Formability Tests – Bendability

Three type of bending tests are widely used:

- **Simple bend test** – flat bend over a fixed radius
- **Wedge bend test** – a punch is used to bend the specimen between two rollers
- **3-point bend test** - a punch is used to bend the specimen between two fixed supports
Simulative Formability Tests – Bendability

Hemming Performance Evaluation

Step 1

Step 2

Legend:

5 No visual defect
4 Mild surface roughening
3 Severe surface roughening
2 Small surface cracks
1 Continuous surface crack
Aluminum Stamping Practices

Cold forming – blanks formed at room temperature
Warm forming – blanks formed at 200~300 °C
Hot forming – blanks formed at 400~500 °C

5xxx – for inner panels only, mostly cold formed, can be warm/hot formed as well
6xxx – for inner panels, mostly cold formed, can be warm/hot formed as well
6xxx – for outer panels, cold formed only
7xxx – for inner structural parts, mostly hot formed, can be cold formed with W-Temper

Unialloy concept
• 6xxx can be used to replace 5xxx for closure inner panels (door/decklid/liftgate)
• Used together with 6xxx closure outer panels,
• No scrap sorting is necessary to optimize resale value of scrap
From Concept To Production

Concept Design → Product Design → Product Engineering → Production Planning

Process Engineering → Die Design & Engineering → Tryout → Production
Aluminum Stamping Press Lines

Tandem

- Typically 5 stand alone press layout
- For bigger panels (bodyside, etc.)
- Large investment required
- Higher manufacturing and maintenance cost
- Low productivity

Transfer

- Single press with huge bed
- Full die set mounted on press shoe that moves together
- For mid-size parts (fender, etc.)
- Moderate investment required
- Relatively lower manufacturing and maintenance cost
- Relatively higher productivity

Progressive

- Single press with huge bed
- Full die set mounted on press shoe that moves together
- For small-size parts (inner structural reinforcements, etc.)
- Lower investment required
- Very low manufacturing and maintenance cost
- Very high productivity
Aluminum Stamping Process

OP 10
Blanking

OP 20
Draw

OP 30
Trim Cam
Trim Pierce

OP 40
Trim Cam
Trim Pierce

OP 50
Flange Cam Flange

OP 60
Flange Cam
Flange Restrike
Developed Blanks

- Majority of stamped BIW parts are made from monolithic blanks
- A developed blank is recommended when the part formability is a concern
- Together with an optimized drawbead layout and profiles give precise control on material flow and maximize the material formability potential

- Tailor welded blanks (TWB) are used for BIW inner panels
- Usually made from sheets with different thicknesses and material properties
- It is a good solution for vehicle lightweighting while maintaining superior part integrity and functional performance
Aluminum Stamping - Feasibility

Splits in drawing operation

- Splits occurred in the mid of the panel
- No die design change can help
- Material forming limits exceeded
- Part redesigns are needed

- Splits occurred close to blank boundary
- Die redesign or process changes are needed
- Part redesigns are not necessary
Splits in flanging operation

Uniaxial stress state, controlled by uniform elongation
Aluminum Stamping - Feasibility

Edge cracking

- Caused by cut edge quality of blanks and excessive stretch along the cut edge
- Tooling effects: clearance, shear angle, cutting speed, …
- Laser cut is an alternative to die cutting
Aluminum Stamping - Quality

Wrinkles

First contact gathering too much local material

Not enough restraining force to control mat flow

Flange width too large or incorrect flanging die path

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Skid/Impact Lines

**Impact lines shown on the panel exposed area.**

**Skid line moves beyond the trim line and show on the class A surface.**

**Skid/impact lines:**
- Surface marks or scratches on panel exposure areas
- Can be masked during painting process
- Ideally, conditions which lead to these lines are resolved during die design stage
Springback:
- The elastic deformation recovery of sheet metal after removing the forming load
- If not controlled, part geometric shape and dimensions are affected
- Ideally, it is compensated for during die design and press tryout stages
- Influencing factors- material properties, die design, stamping stroke rate, die wear, …
Aluminum Stamping - Manufacturing

- **Destacking**
  - Aluminum is non-magnetic and needs to be transferred with specific ways such as vacuum cups

- **Productivity**
  - Associated with die wear, tooling maintenance, ……

- **Tooling Maintenance**
  - Aluminum is softer and more easily scratched, affecting surface quality. Good tooling maintenance schedule and practice are necessary

- **Lubrication**
  - Good lubrication practice significantly improves formability, quality and productivity

- **Scrap Management**
  - In order to optimize scrap value, 5xxx alloys and 6xxx alloys must be sorted to keep separate
Aluminum Stamping - Manufacturing

Die wear and build-up

- Aluminum is softer and is more easily scratched over small die radii, especially after a certain number of stamping strokes.
- Severe scratches, in the direction of sliding, arise from the ploughing of tiny aluminum particles which are stuck to the die surfaces.
- This leads to die wear and aluminum build-up on the die surfaces.
- For aluminum stamping, it is necessary to have a good heat treatment and coatings on die surfaces.
- Use of Electro Discharge Texturing (EDT) surface plus dry film lubricant will significantly improve die wear and build-up.
Galling:
- Transfer of blank material to surface of the die
- Increases friction which may lead to die damage if not controlled
- Conditions which lead to Galling can be reduced or prevented by:
  - Use of proper lubricants (prelube, dry lube)
  - Surface hardening of the tooling
  - Polishing die surfaces
  - Use of PVD coatings
  - Conducting regular die maintenance
Lubrication

- Needed to reduce friction and avoid galling and build up
- Two types of lubrication are widely used
  - Mineral oil based -
    - more easily applied during blank wash
    - is easily removed before painting process
  - Dry lubricants -
    - are usually applied during coil passivation and heat treatment process
    - provide more stable frictional behavior
    - good for process stability
    - TriboForm Technical Case
The friction coefficient is mainly determined by the lubrication regime.
• full film lubrication case - friction is relatively low.
• boundary lubrication case - entire load is carried by direct metal-to-metal contact between tool and blank, friction is much higher.
• In aluminum stamping, the lubrication regime is somewhere between full film and boundary lubrication.

**Sheet surface finish:**
• roughness and waviness can largely change the lubrication regime.
• EDT finish has a relatively higher roughness, which is capable of generating micro-pockets containing lubricant.
• These micro reservoirs may act as a source of extra lubrication in the process of severe asperity flattening, and thus shift the lubrication regime closer to full film lubrication.
Questions?
Quiz

1. Open a browser on your laptop, tablet or mobile device

2. Visit: pollev.com/aassociation001

3. Answer the questions based on knowledge from this session.
Sheet metal formability can be fully evaluated by means of FLC test.

Split issue can always be solved by using a more formable Material, no matter how the die is designed.

Wrinkling issue is not associated with the part design, but with stamping die design and processing.

Springback is a material property, which cannot be controlled by stamping die design and processing.

Aluminum outer and inner panels have different stamping quality requirements, which depend on their functions.
Presenter

Tamer O. Girgis, Ph.D.
• Aleris
• Surface Treatment R&D/Sr. Applications Engineering
Joining Outline

• Objective: Provide an introductory class on aluminum alloy joining processes with the focus on BIW and closure applications. Importance of welding of aluminum and its alloys with respect to material joint properties, joint evaluation, typical joining methods, joining processes and its associated challenges.

1. Material property, difference between aluminum alloys and steels
2. Material property testing and key parameters (Uniaxial tensile test, bulge test, …)
3. Joining processes evaluation
4. Joining processes and its automotive applications
5. Joining challenges and its remedies
6. 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

Electrical

Chemical

Mechanical

Fastening
Seaming
Crimping
Stitching

Oxyfuel gas
Thermit

Arc
Resistance
Electron beam
Laser beam

Resistance

Diffusion
Explosion

Cold
Friction
Ultrasonic
There are multiple joining options for Al, each presents challenges, but none are technical show-stoppers.

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&lt;br&gt;• Inspection method&lt;br&gt;• Common infrastructure &amp; capital&lt;br&gt;• Cannot join dissimilar materials&lt;br&gt;• Specific rivet &amp; tooling for each stack-up /material combination&lt;br&gt;• High deformation limits materials to be joined&lt;br&gt;• Speed of Installation&lt;br&gt;• Weight &amp; Cost&lt;br&gt;• Backside Protrusion&lt;br&gt;• Durability&lt;br&gt;• Curing Conditions&lt;br&gt;• Always in combination with spot-based joining</td>
</tr>
<tr>
<td>Self-Piercing Rivets</td>
<td></td>
</tr>
<tr>
<td>Flow-Drill Screws</td>
<td></td>
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<tr>
<td>Adhesive Bonding</td>
<td></td>
</tr>
</tbody>
</table>
Automotive RSW Lines – Flexibility is King

- Multiple automotive models flow down single resbot 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 resbot line

RSW process flexibility enables OEMs to make gauge or product changes without the downtime and capital costs to retool.
But … aluminum and 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

- 53 different component materials
- 17 different joining methods
- ~8,000 joining elements

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

![Images of Bolted, Riveted, and Welded connections]
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: It is 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

- Fusion Welding
  - Liquid Metal Welding
  - Gas Welding
  - Resistance Fusion Welding
  - Arc Fusion Welding
  - Electron Beam Welding
  - Laser Beam Welding
  - Cast Welding
  - Alumina Thermit Welding
  - Electroslag Welding
  - Gas Shielded Tungsten Arc Welding
    - Tungsten Inert Gas Welding
    - Plasma Arc Welding
    - Atomic Hydrogen Welding
    - Manual Metal Arc Welding
    - Gravity Arc Welding
    - Firecracker Welding
    - Flux Cored Metal Arc Welding
  - Narrow Gap Welding
  - Electro Gas Welding
  - Plasma Mig Welding
  - Inert Gas Metal Arc Welding
  - Active Gas Metal Arc Welding
    - CO₂ Welding
    - Gas Mixture Shielded Metal Arc Welding

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Resistence 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)

1. Components inserted between electrodes
2. Electrodes Close; Force Applied
3. Current ON
4. Current OFF
5. 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></th>
<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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<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>
<td>7.1</td>
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<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>
<td>8.6</td>
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<tr>
<td><strong>Minimum Weld Spacing (mm)</strong></td>
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<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>
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<tr>
<td><strong>Minimum Edge Distance (mm)</strong></td>
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<td>5.6</td>
<td>6.4</td>
<td>7.9</td>
<td>9.5</td>
<td>11.1</td>
<td>12.7</td>
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<tr>
<td><strong>Minimum Overlap (mm)</strong></td>
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<td>11.1</td>
<td>12.7</td>
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<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
- Arconic’s new robotic RSW cell has process capabilities to effectively weld the ultra-high strength grades
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>
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<tr>
<th>Metal Thickness (mm)</th>
<th>0.60</th>
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<th>1.60</th>
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<th>2.30</th>
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<td><strong>Radius (mm)</strong></td>
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<tr>
<td>Truncated</td>
<td>50.8</td>
<td>76.2</td>
<td>152.4</td>
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<tr>
<td><strong>Electrode Diameter (mm)</strong></td>
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<td>15.9</td>
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<tr>
<td><strong>Electrode Face Diameter (mm)</strong></td>
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<td>Radiused</td>
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<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>
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<td>3.1  (700)</td>
<td>3.8  (850)</td>
<td>4.1  (820)</td>
<td>4.6  (1040)</td>
<td>5.1  (1150)</td>
<td>5.6  (1250)</td>
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<td><strong>AC Welding Current kA RMS</strong></td>
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</table>
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

1. Rotating part, no contact;
2. Parts brought into contact to generate friction heat;
3. Rotation stopped and axial pressure applied;
4. 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
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:

1. Adhesives
2. Self-pierce rivets (SPR)
3. Clinching
4. 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.

(Source: Henrob)

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

In principle stronger than clinching.
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)

No Adhesive

With Adhesive

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.
Flow Drill Screws

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 are 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:

- RPM
- Torque
EJOT® Flow Drill Screws

Lap Shear Joint w/Pilot Hole

Lap Shear Joint w/o Pilot Hole
EJOT® Flow Drill Screws

EJOT Average Lap Shear Data

Joint Strength (kN)

Alloy

5754-0
6013-T4
6013-T6
6022-T4
7075-T6

w/o Adhesive_No Pilot
w/o Adhesive_7mm Pilot
w/Adhesive_No Pilot
w/Adhesive_7mm Pilot
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>
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<tr>
<td>Friction Stir Spot Welding</td>
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<tr>
<td>Laser Welding / Laser Brazing</td>
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<tr>
<td>Fasteners (SPR, FDS, Nails)</td>
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<td>Clinching</td>
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<td>Adhesive Bonding</td>
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<tr>
<td>Magnetic Pulse Welding</td>
<td>★</td>
<td>★</td>
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<td></td>
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</table>

*GM Patented Process

Source: CAR 2017
Questions?
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!