Joining Aluminum and Other Materials

The Aluminum Transportation Group

Presenter

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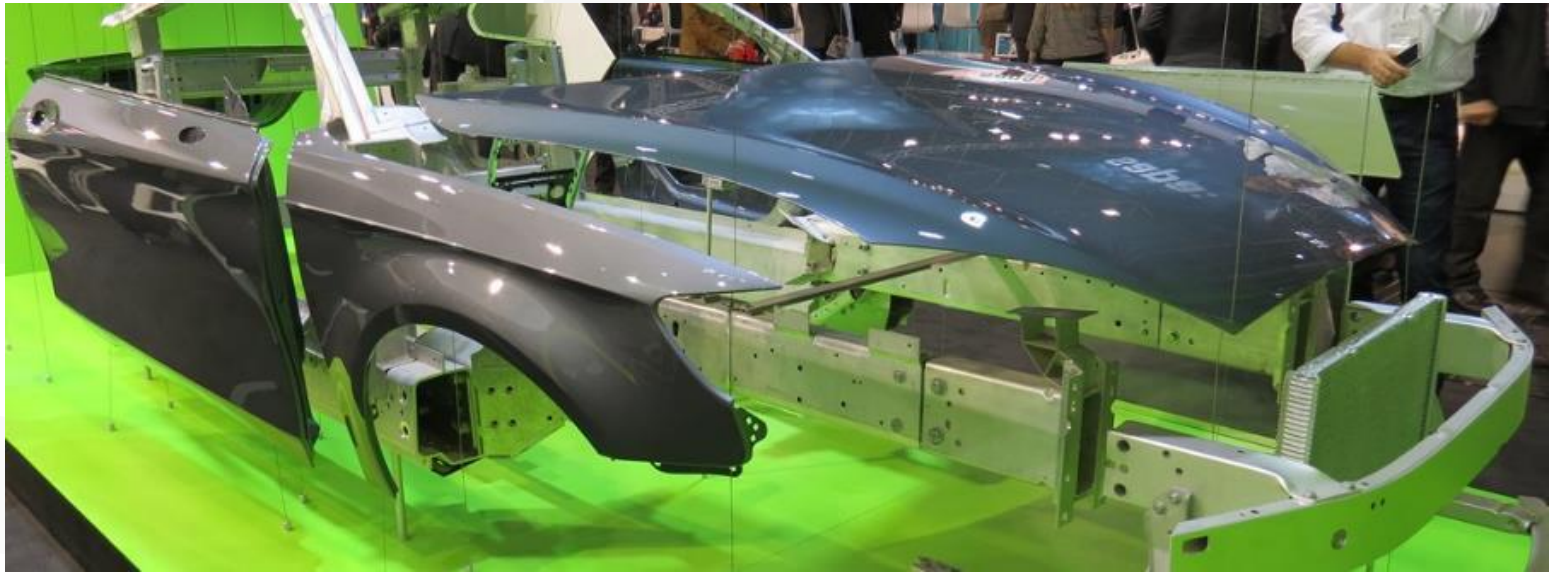
Surface Treatment R&D/Sr. Applications Engineering

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

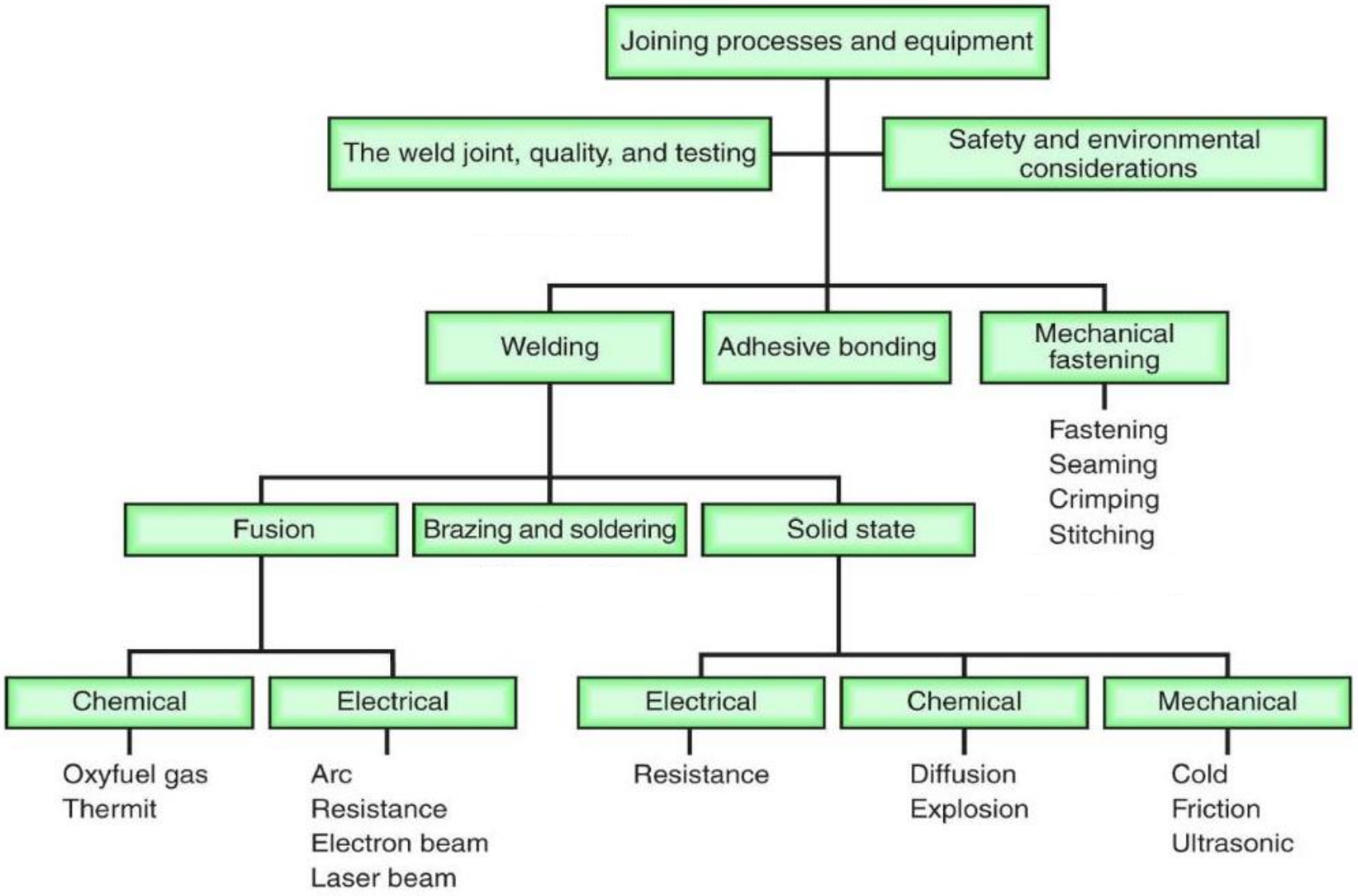
- Low relative density (~ 2.7)
- Reasonably high tensile strength and ductility
- High strength to weight ratio
- Excellent electrical and thermal conductivity
- Corrosion resistance
- Easy fabrication



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



Current Joining Options for High-Volume Auto Sheet Components

Joining Method	
	**Resistance Spot Welding**
	**Self-Piercing Rivets**
	**Flow-Drill Screws**
	**Adhesive Bonding**

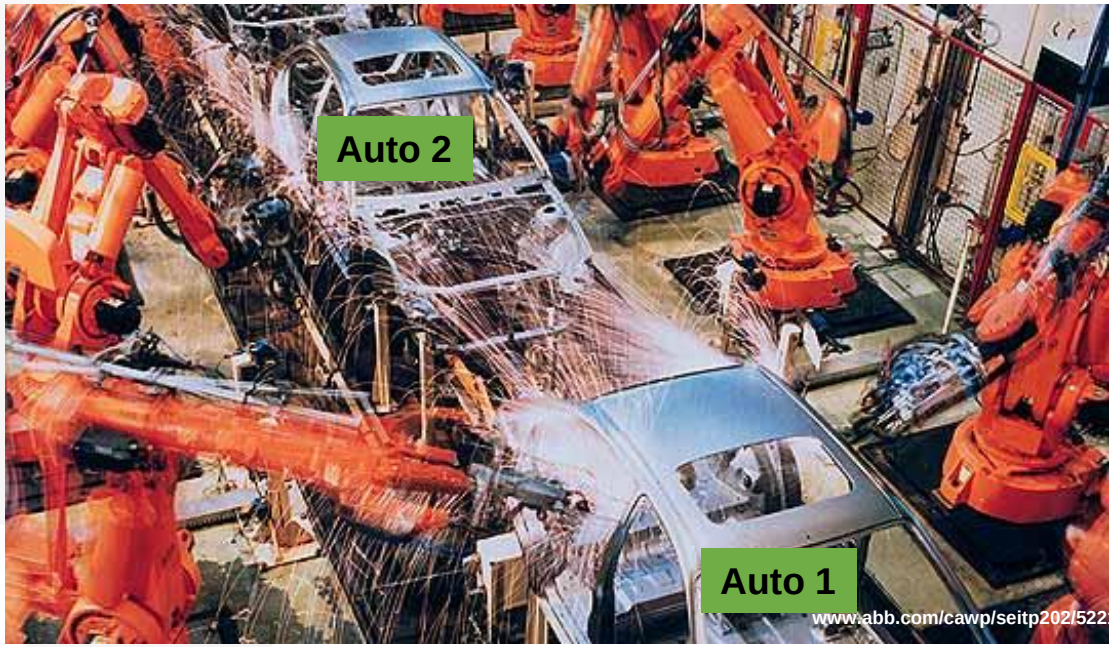
Challenges

- Reliability & consistency w/ Al
- Inspection method
- Common infrastructure & capital
- Cannot join dissimilar materials
- Specific rivet & tooling for each stack-up/material combination
- High deformation limits materials to be joined
- Speed of installation
- Weight & cost
- Backside protrusion
- Durability
- Curing conditions
- Always in combination with spot-based joining

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

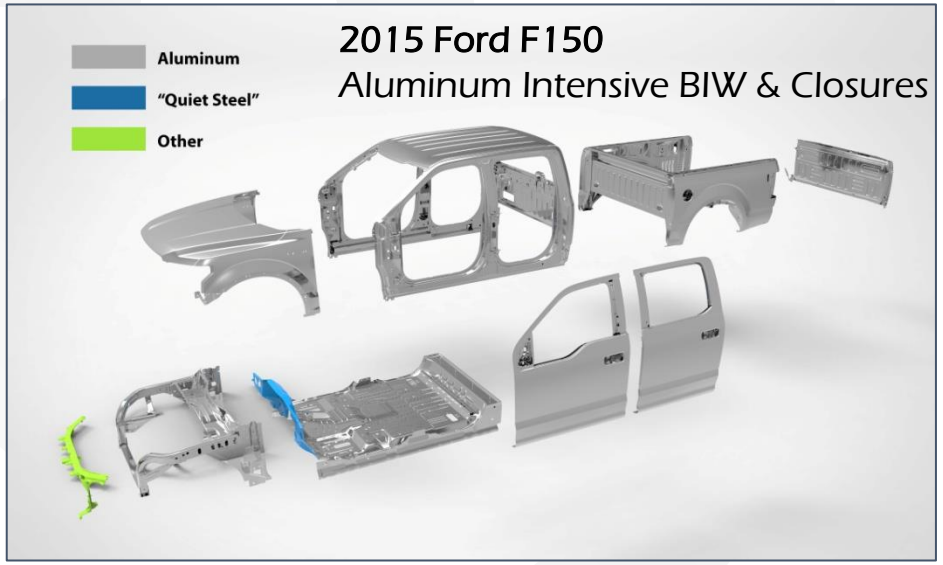
Example – Two different auto assemblies run down the same respot line

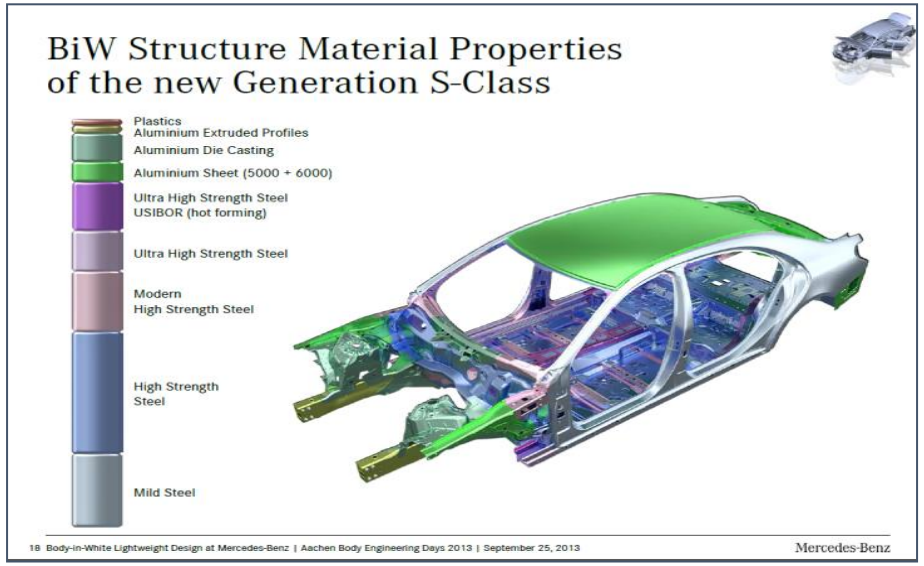


RSW process flexibility enables OEMs to make gauge or product changes without the downtime and capital costs to retool

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





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

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

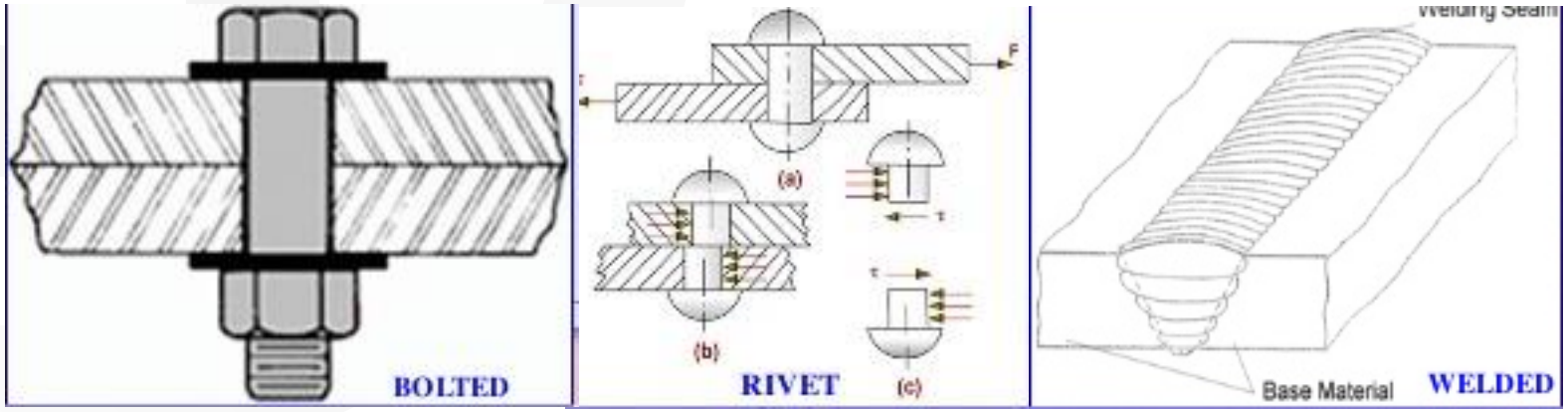
Metal Joining Process Overview

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

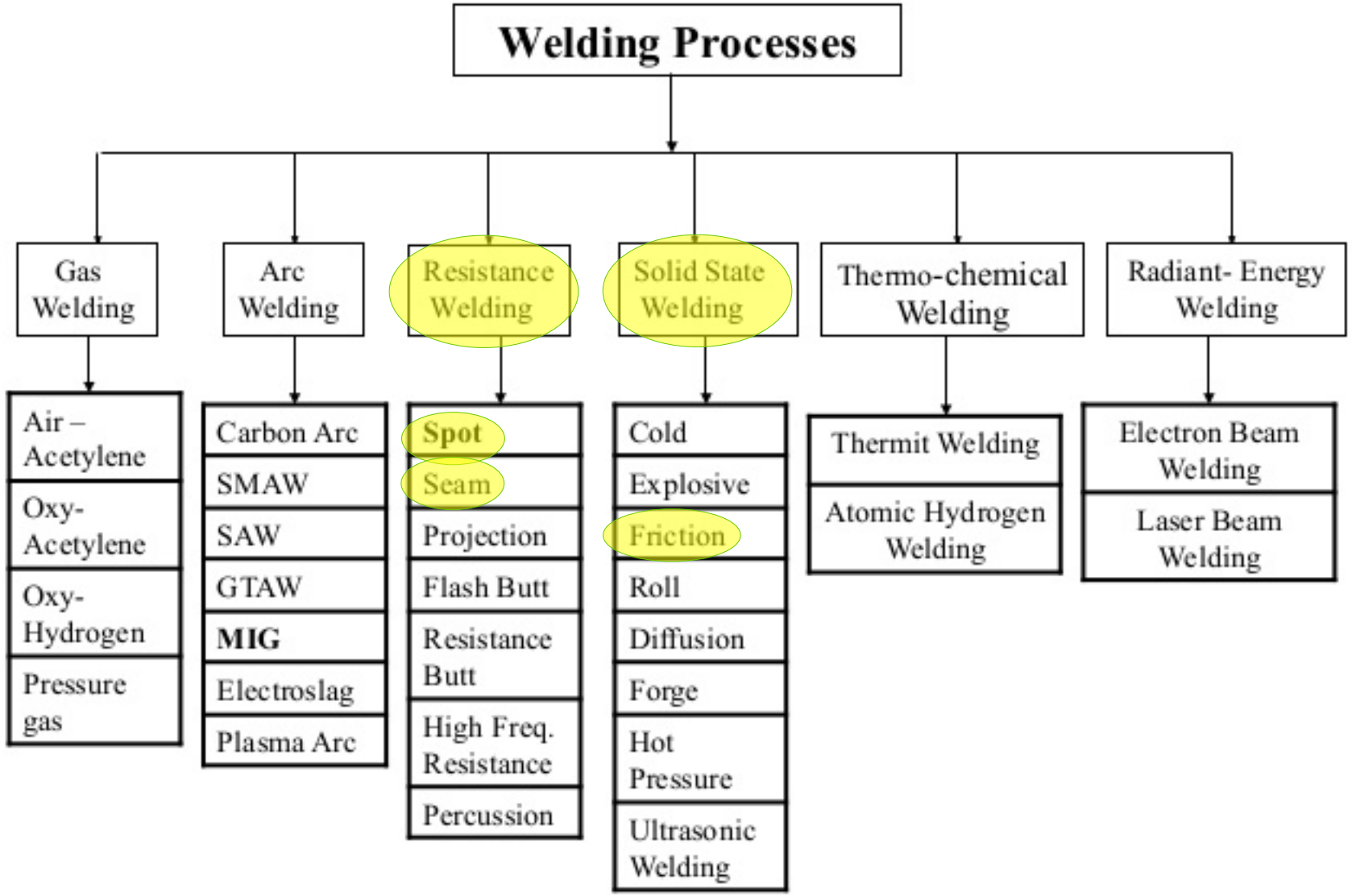
- Fusion Welding: Coalescence is accomplished by melting the two components to be joined, in some cases adding filler metal to the joint.
  - Examples: Arc welding, resistance spot welding (RSW), oxyfuel gas welding
- Solid State Welding: Heat and/or pressure are used to achieve coalescence, but no melting of base metals occurs and no filler metal is added.
  - Examples: Friction welding, forge welding, diffusion welding

Aluminum Alloys Weldability

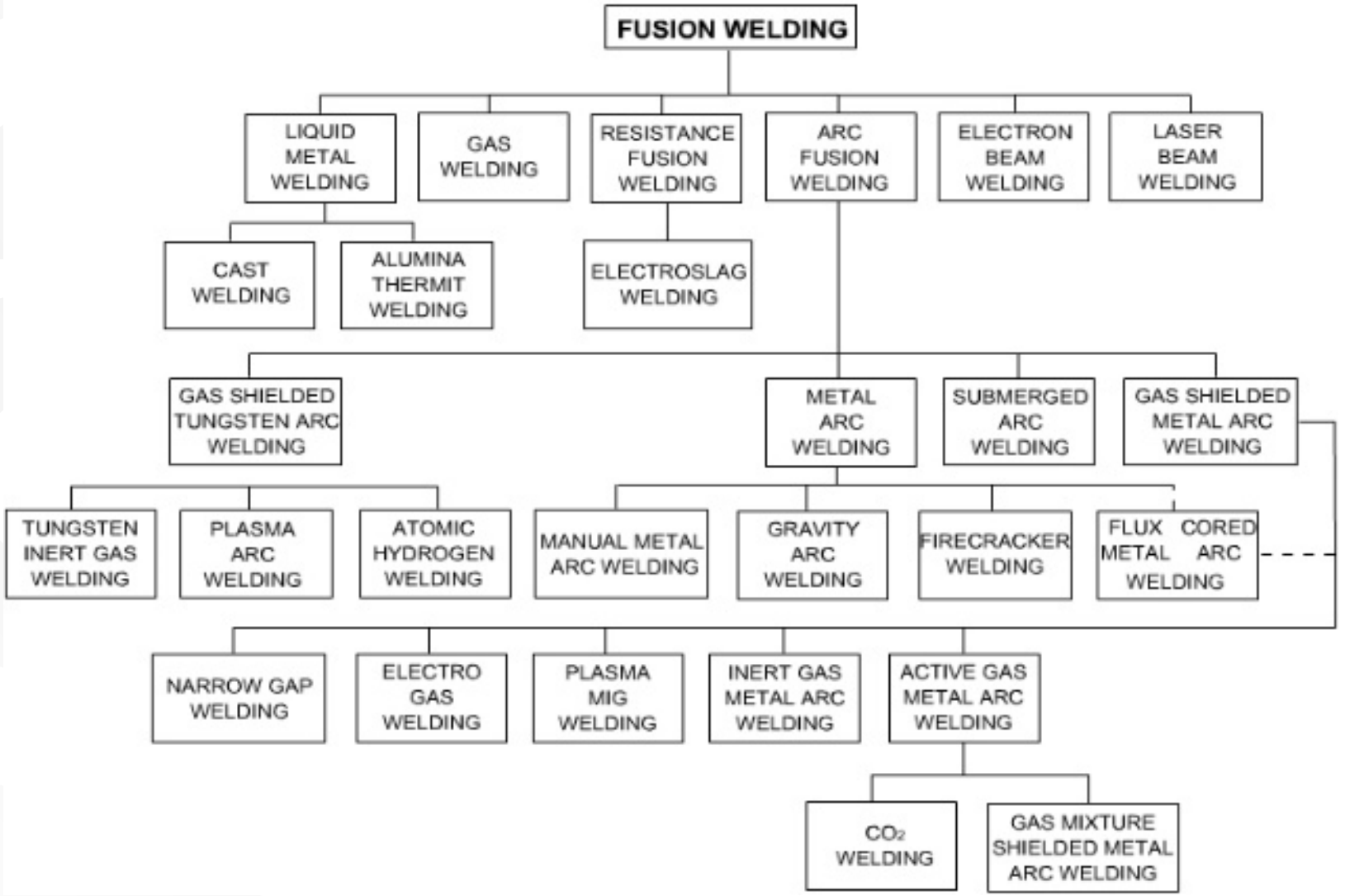
Definition: The resistance of the weld metal to solidification cracking and porosity.

- 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



Classification of Welding Processes



Resistance Welding (RW)

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

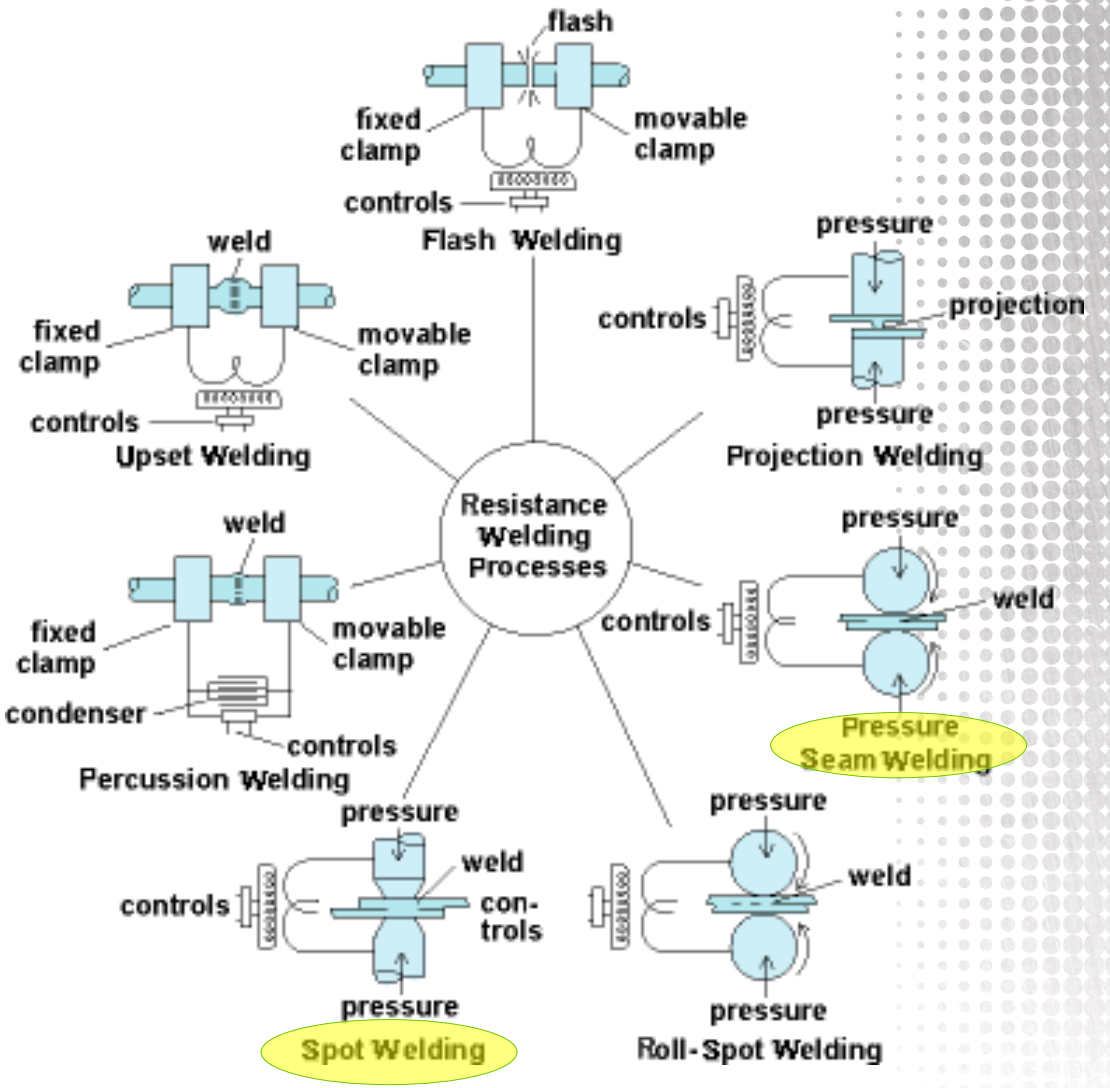
- Heat generated by electrical resistance to current flow at junction to be welded
- Resistance spot welding (RSW) is the main process in the RW group

Advantages:

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

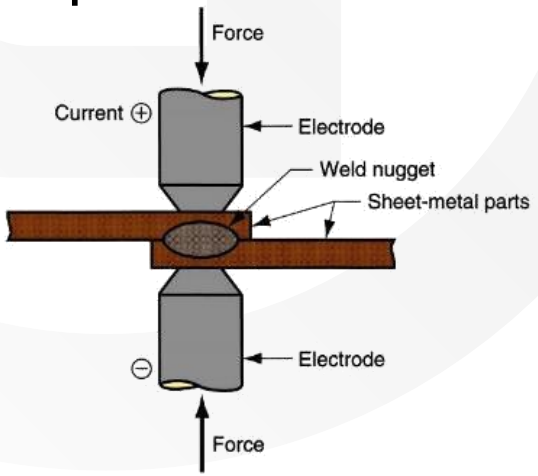
Limitations:

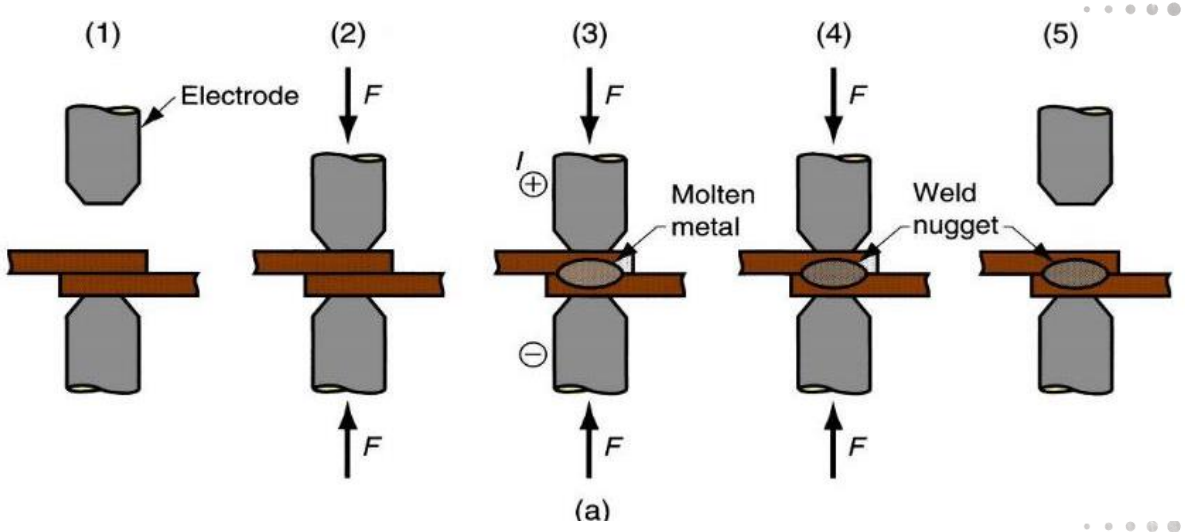
- Limited to lap joints



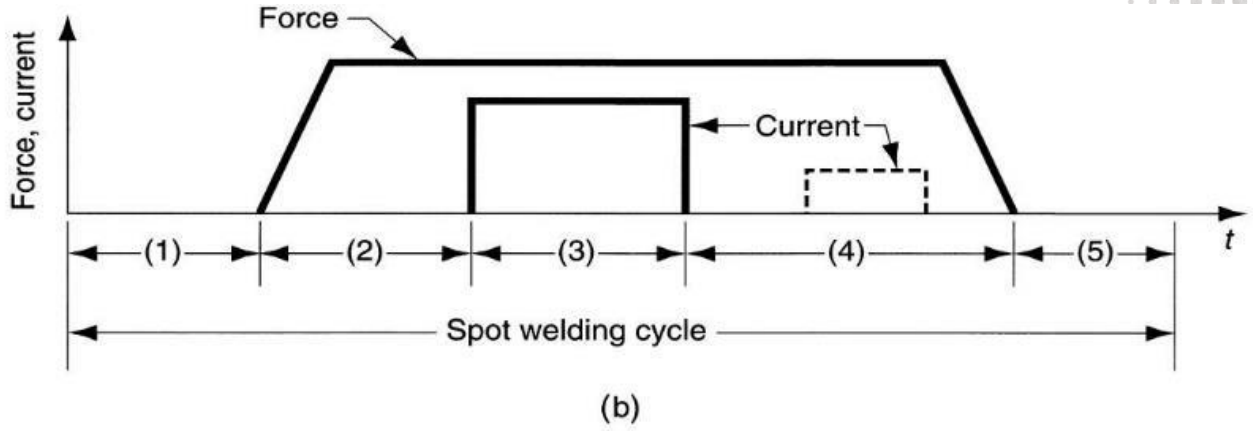
Resistance Spot Welding (RSW)

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





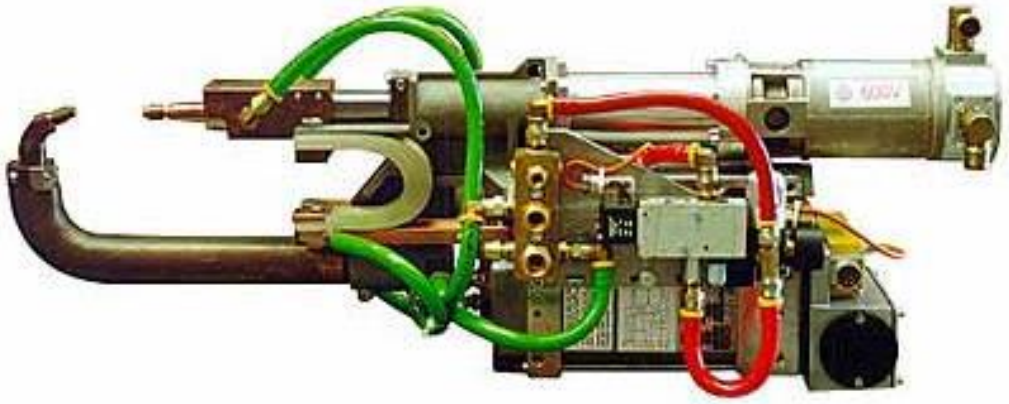
Resistance Spot Welding Cycle



Force and Current Plot

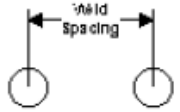
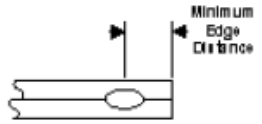
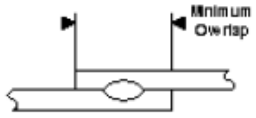
Resistance Spot Welding Equipment

Robotic Spot Welding System
Source: Kuka Systems



Servo-controlled Spot Welding Gun
Source: ARO

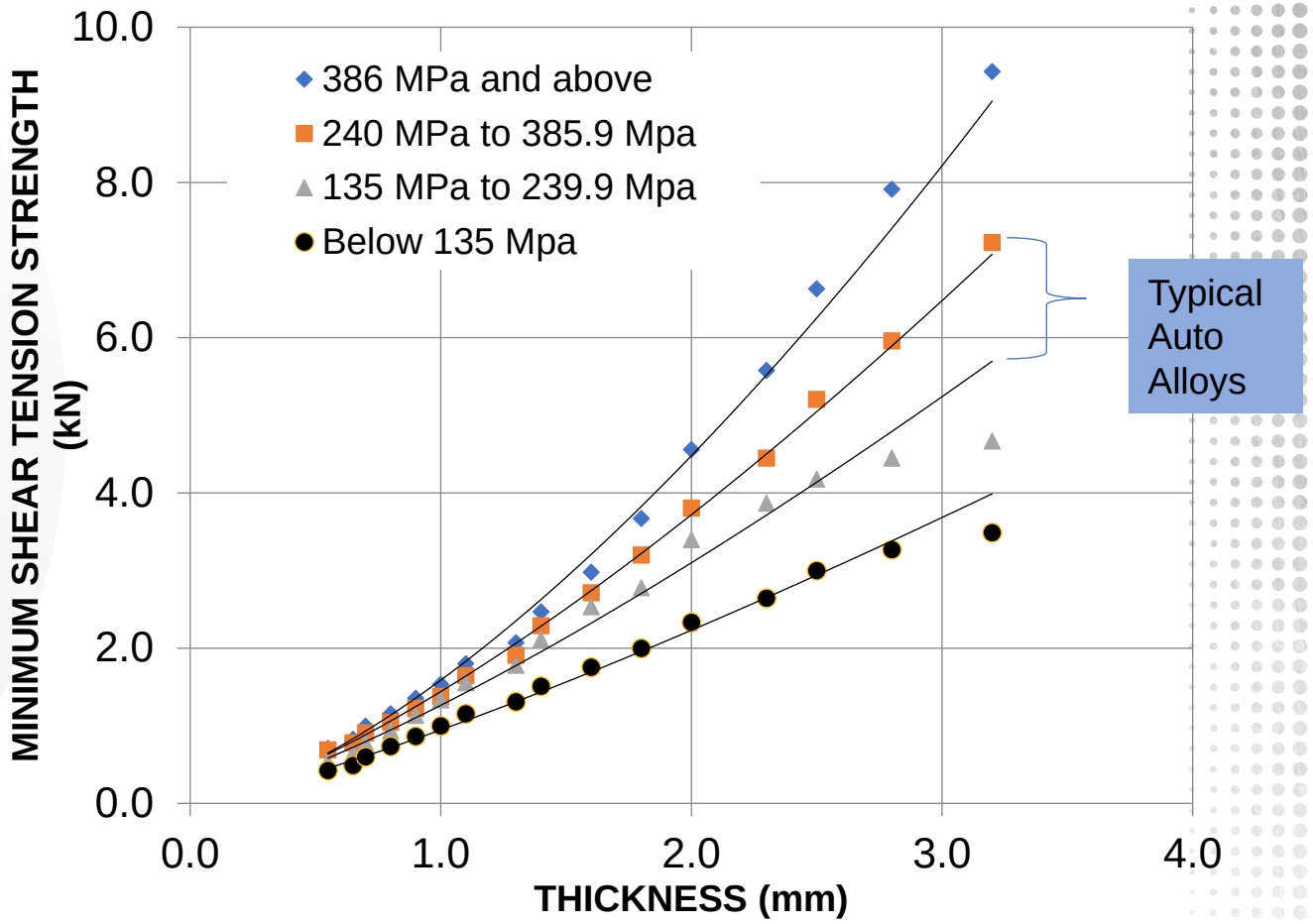
Minimum Spot Weld Size and Spacing

	Metal Thickness (mm)	0.65	0.81	1.02	1.27	1.60	1.80	2.03	2.29	2.54	3.18
Minimum Weld Button Diameter (mm)	$4\sqrt{t}$	3.1	3.6	4.1	4.6	5.1	5.3	5.7	6.1	6.4	7.1
Recommended Weld Button Diameter (mm)	$5\sqrt{t}$	3.8	4.3	4.8	5.3	6.1	6.6	6.9	7.2	7.6	8.6
Minimum Weld Spacing (mm)		9.5	12.7		15.9		19.0		22.2	25.1	31.5
Minimum Edge Distance (mm)		5.6	6.4		7.9	9.5			11.1		12.7
Minimum Overlap (mm)		11.1	12.7	14.3	15.9	19.0	20.6	22.2	23.8	25.1	28.6

Ref: AA Welding Aluminum, Table 13.1

Tensile Shear Strength Performance of AL Resistance Spot Welds

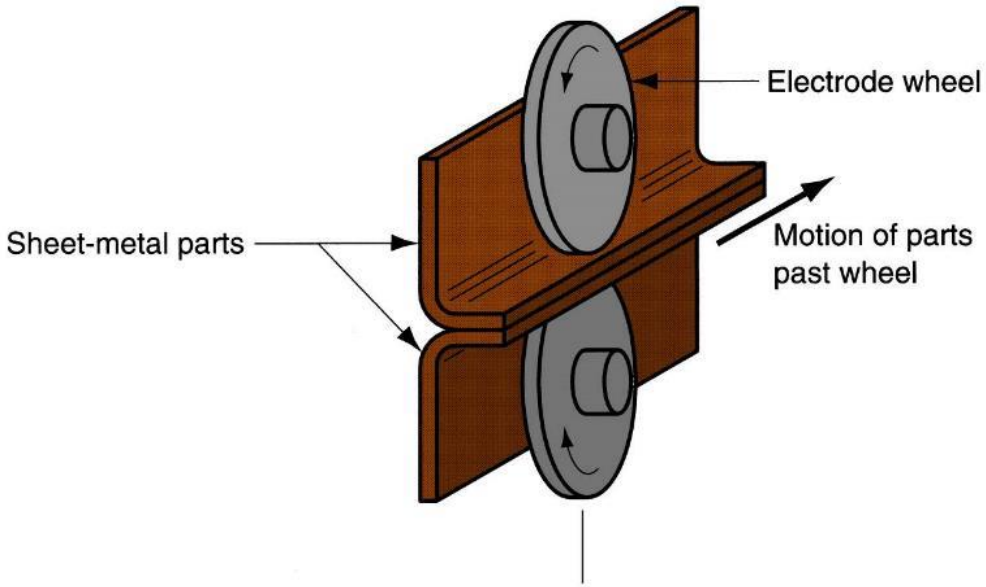
- Typical strength of automotive Al spot welds fall within the middle alloy ranges (150 to 300 MPa)
- Investigating RSW performance of ultra-high strength alloys (>386 MPa) in combinations with similar or lower Al grades
- New robotic RSW cell has process capabilities to effectively weld the ultra-high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



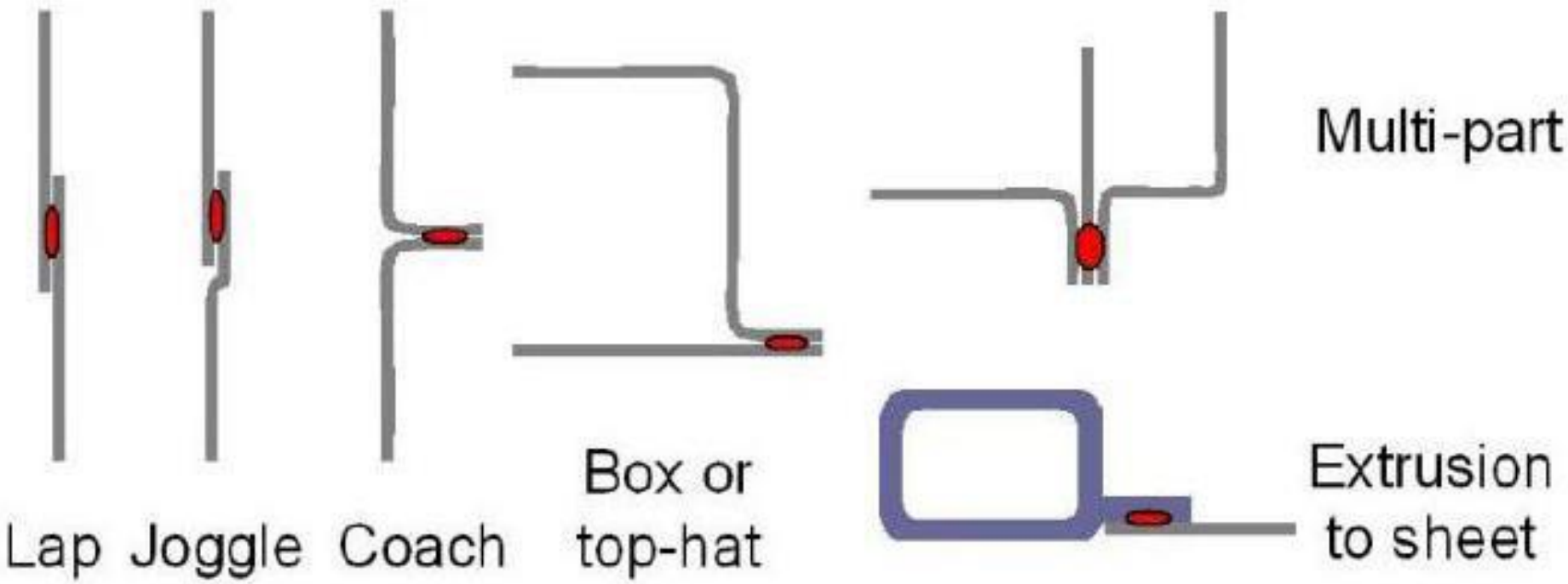
AWS D17.2:2007 Aluminum Tensile Shear Strength

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

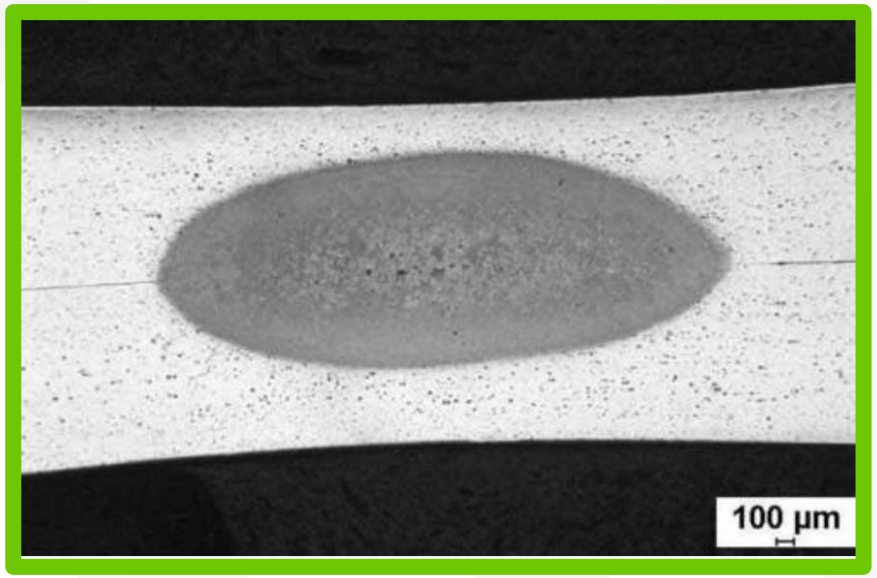


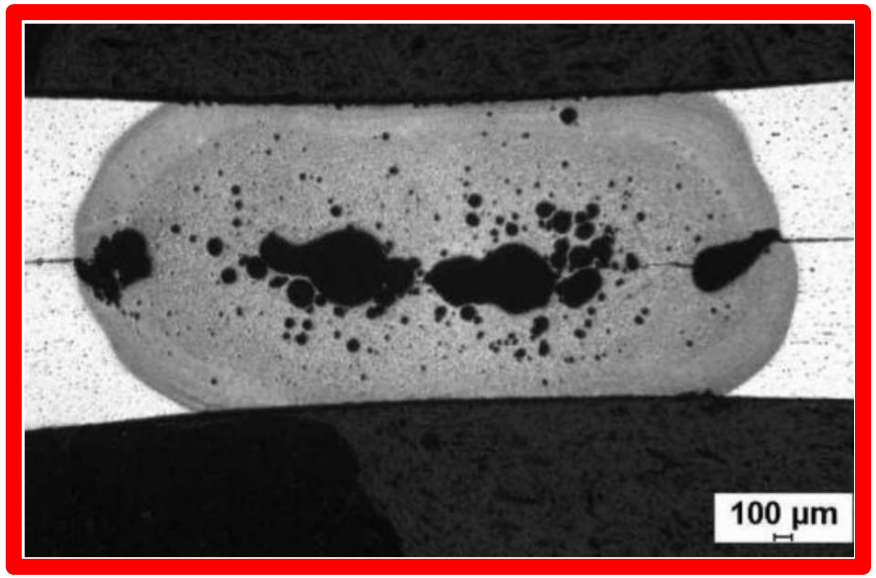
Joint Configurations Suitable for Resistance Spot Welding



- 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



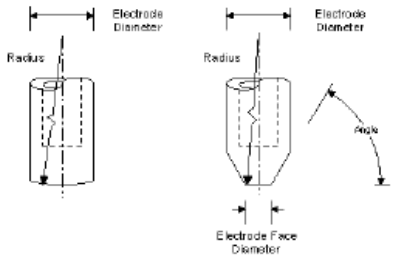


- Ideal aluminum spot weld cross section
- Good nugget shape
- Good penetration
- No cracks
- Minimal porosity

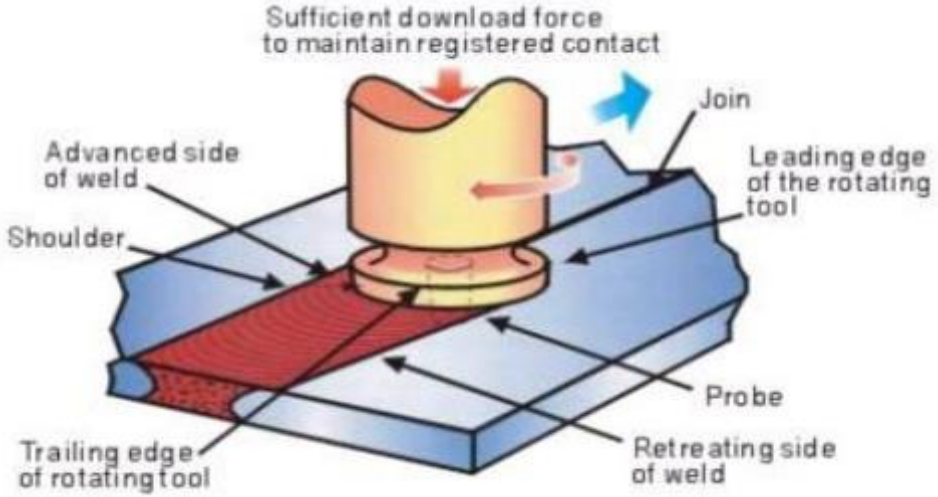
Non-conformities of resistance spot welds are:

- Cold welds
- Too small nuggets
- Cracks, porosity, pores, etc. inside the welding nugget

Typical Aluminum Spot Welding Parameters

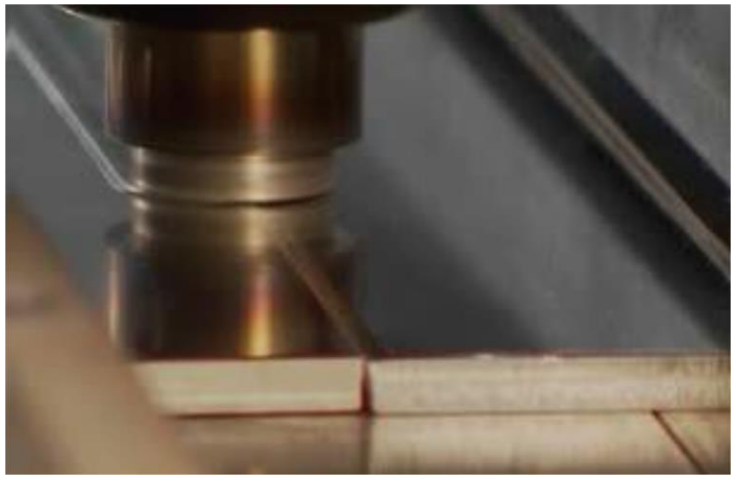
	Metal Thickness (mm)	0.60	0.80	1.00	1.30	1.60	1.80	2.00	2.30	2.50	3.20
Radius (mm)	Radiused Truncated 	50.8		76.2						152.4	
Electrode Diameter (mm)		15.9								22.2	
Electrode Face Diameter (mm)		6.4			7.8		9.4			11.0	
Angle (Degree)		60					45				
Weld Force kN (lbs)	Radiused	3.6 (800)	4.0 (900)	4.5 (1000)			5.3 (1200)	6.2 (1400)	7.1 (1600)	8.0 (1800)	10.7 (2400)
	Truncated	2.2 (500)	2.5 (550)	2.7 (600)	3.1 (700)	3.8 (850)	4.1 (920)	4.6 (1040)	5.1 (1150)	5.6 (1250)	7.1 (1600)
Weld Time	Number of 60Hz Cycles	4			5	6	8		10		12
DC Welding Current kA RMS	As Received Surface	20	22	23	26	30	32	35	37	40	50
	Mechanical and/or Chemically Cleaned Surface	21	24	25	27	31	33	36	38	41	51
AC Welding Current kA RMS	As Received Surface	22	27	28	30	33	36	39	41	44	53
	Mechanical and/or Chemically Cleaned Surface	24	29	30	33	37	39	42	46	48	58

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

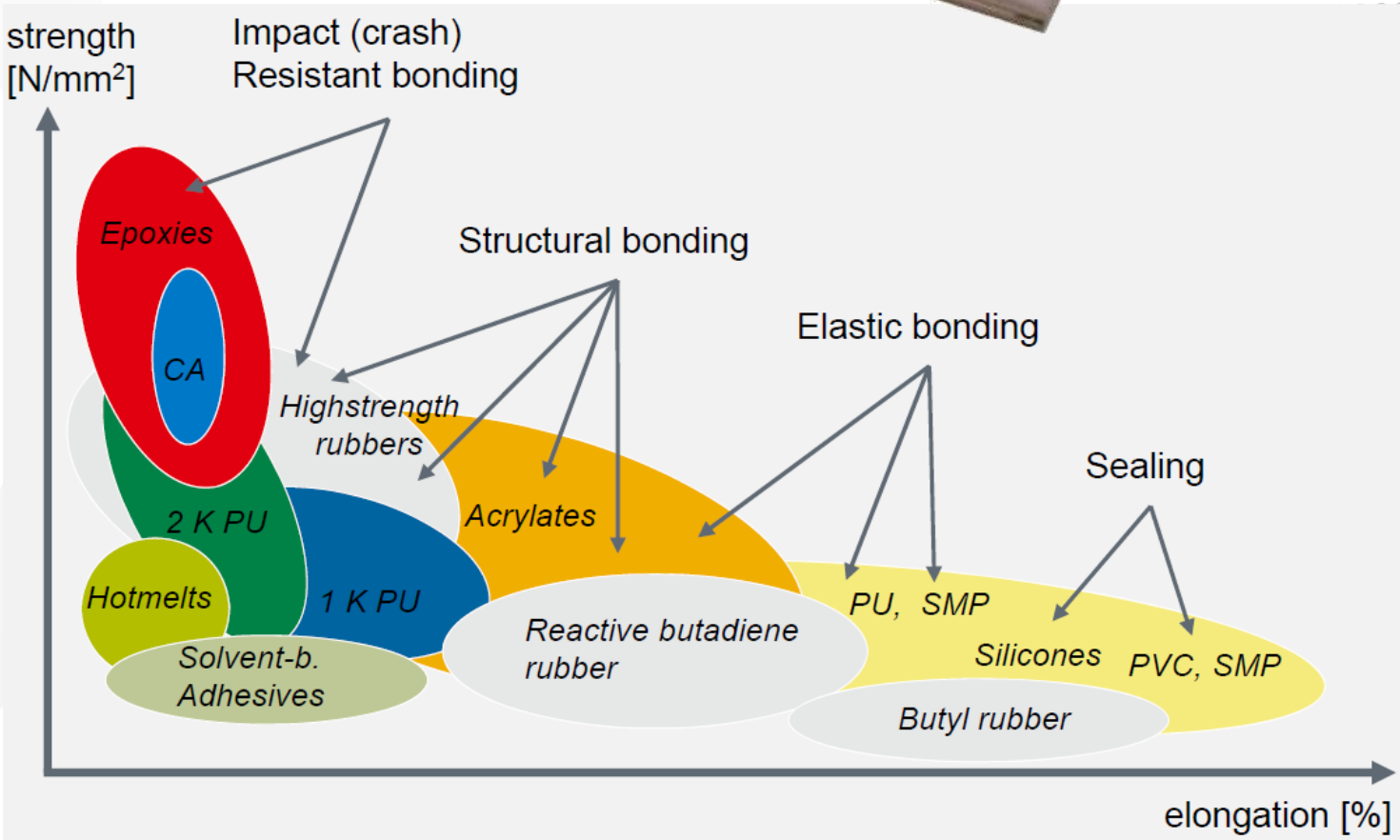
A variety of adhesives exists for very specific applications and requirements

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



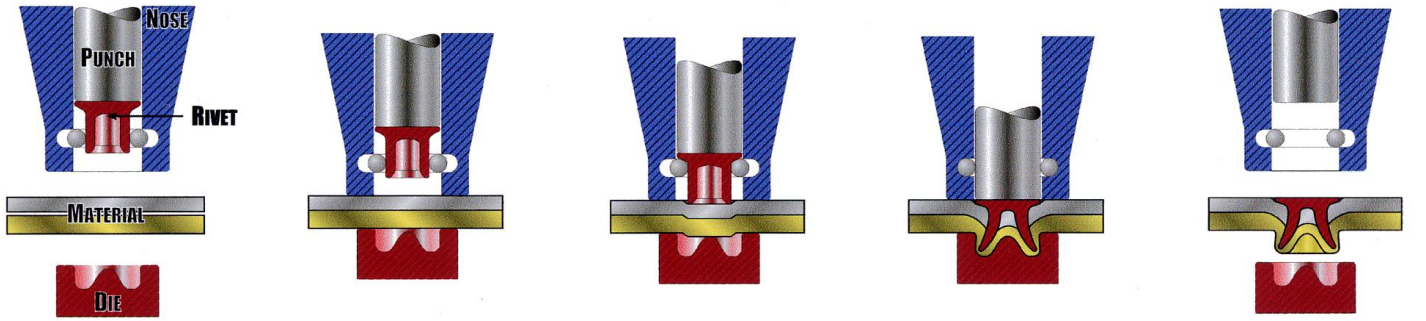
Property Range of Adhesives (Source: Henkel)

Self-Piercing Rivets

Advantages:

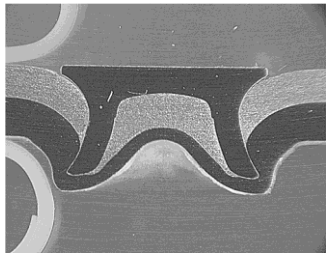
- High-strength joints that are suitable for visual inspection.
- Reproducible and requires no pre-drilling.
- Joints are watertight and airtight.
- Joining both metallic and non-metallic materials and will fasten dissimilar metals.
- Suitable for use with different material strengths and thicknesses.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

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



(Source: Henrob)

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.



Its stronger than clinching.

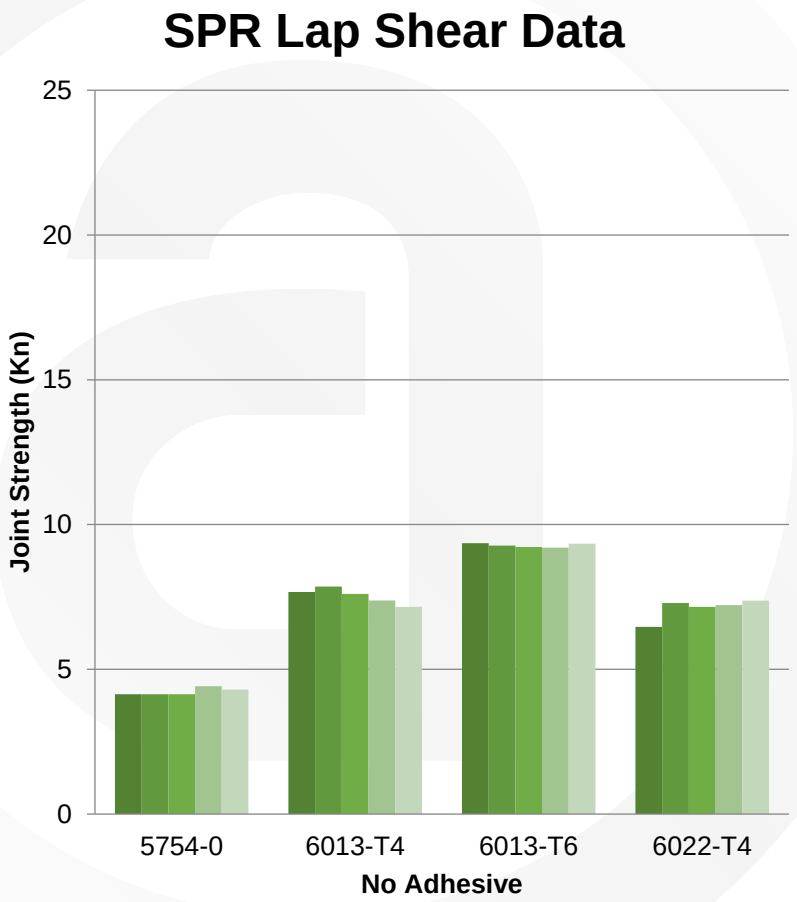
Self-Piercing Rivets

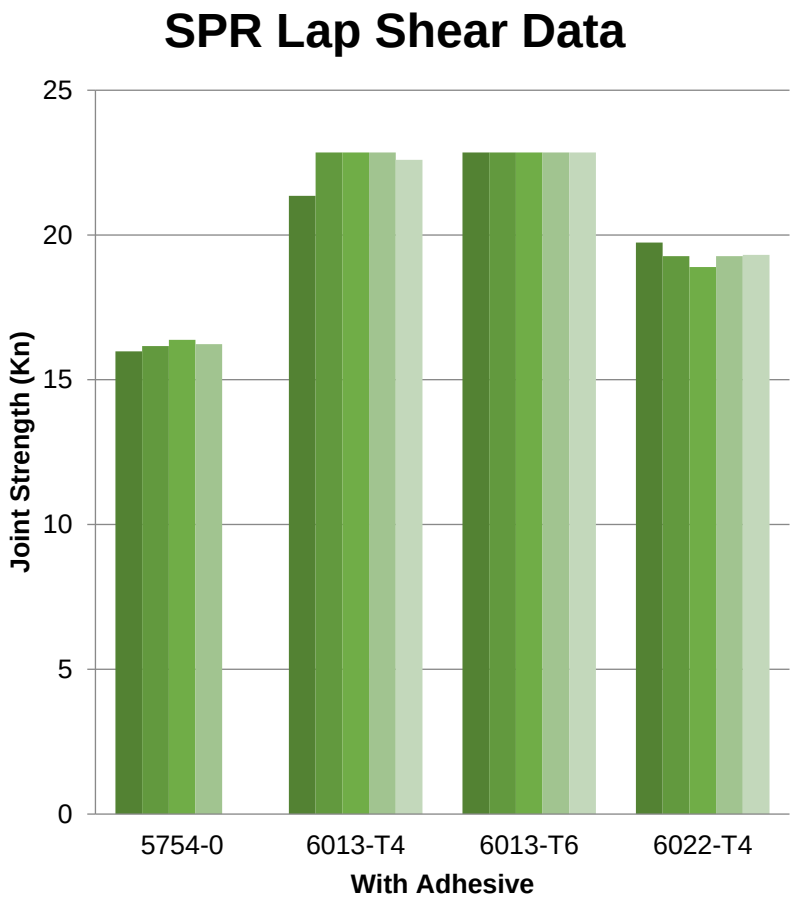
Rivet Cross-Sections

5754-0 Rivet
w/o Adhesive

6013-T6 Rivet
w/o Adhesive

Self-Piercing Rivets

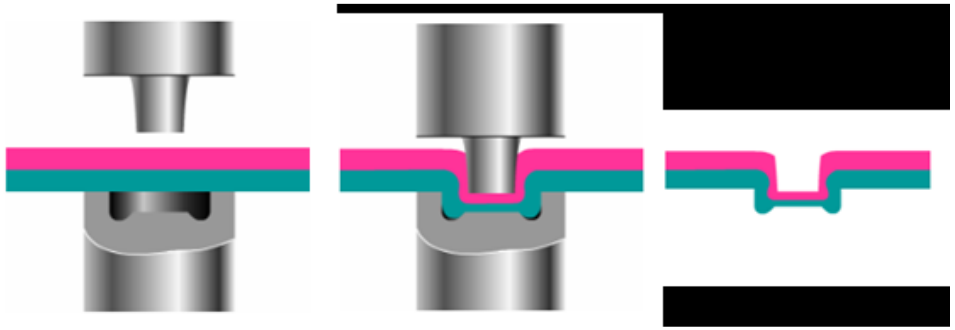




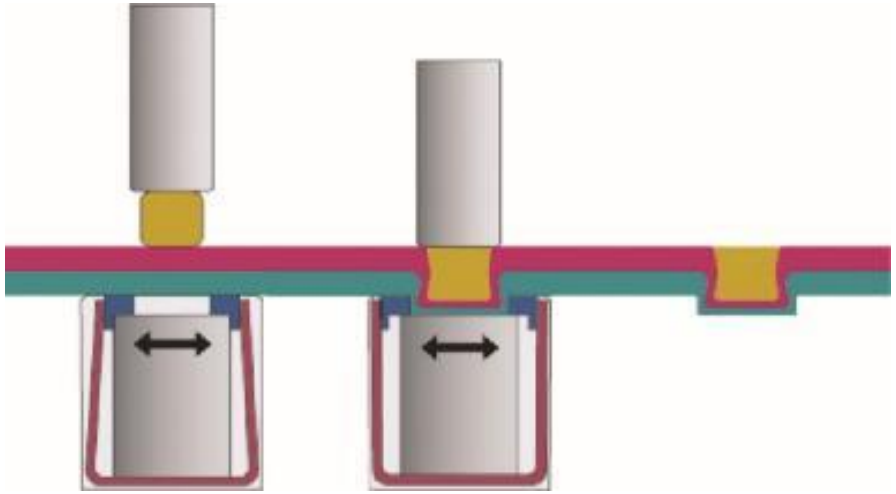
2 mm material (both samples joined were same alloy)

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

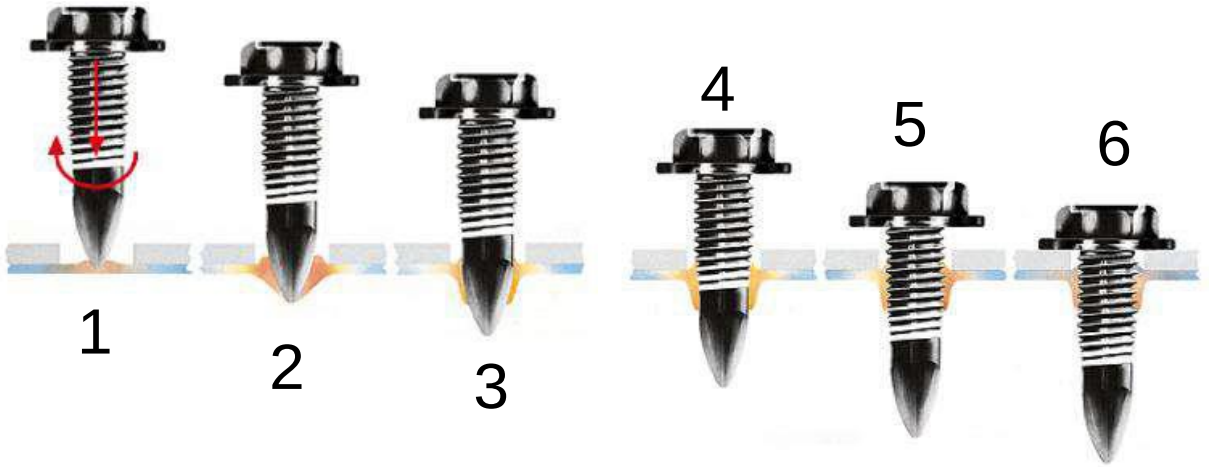


Clinching Process (Source: TOX)



Clinch Rivet Process

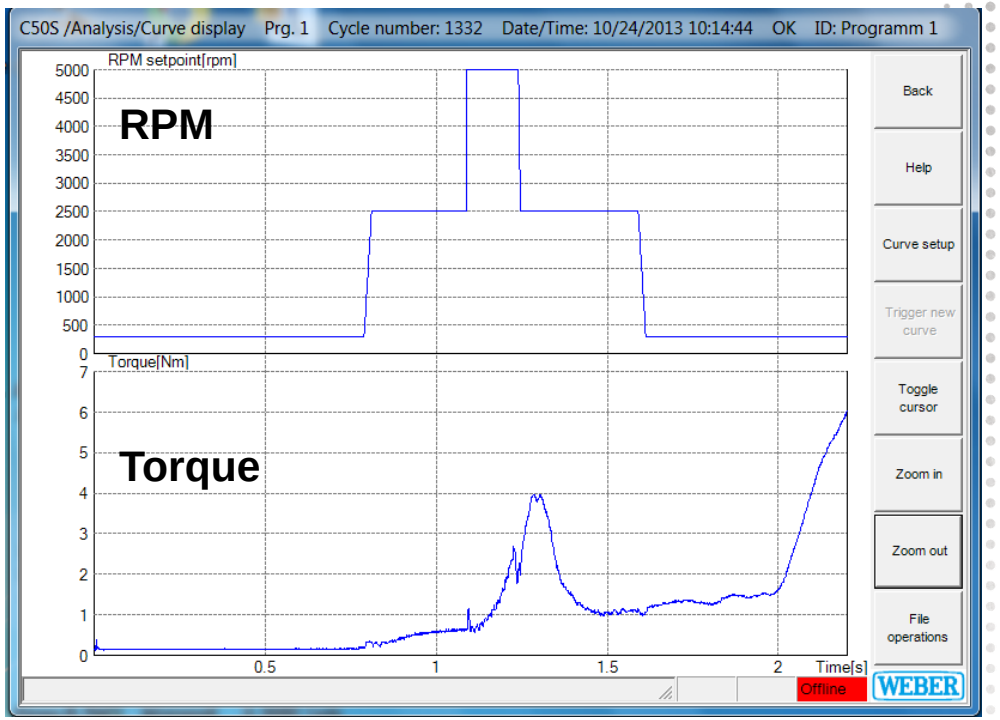
Flow Drill Screws



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 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.

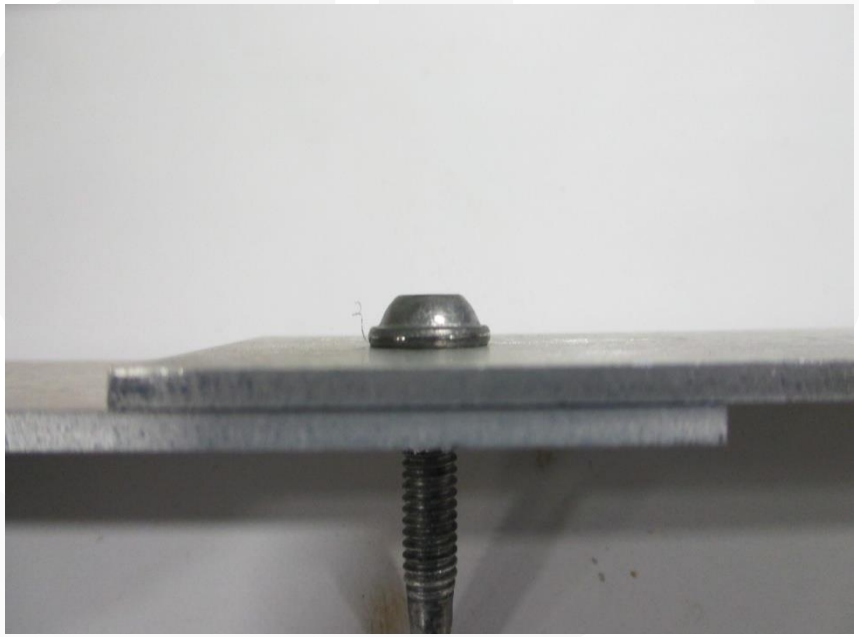
EJOT® Flow Drill Screw

Installation Process:

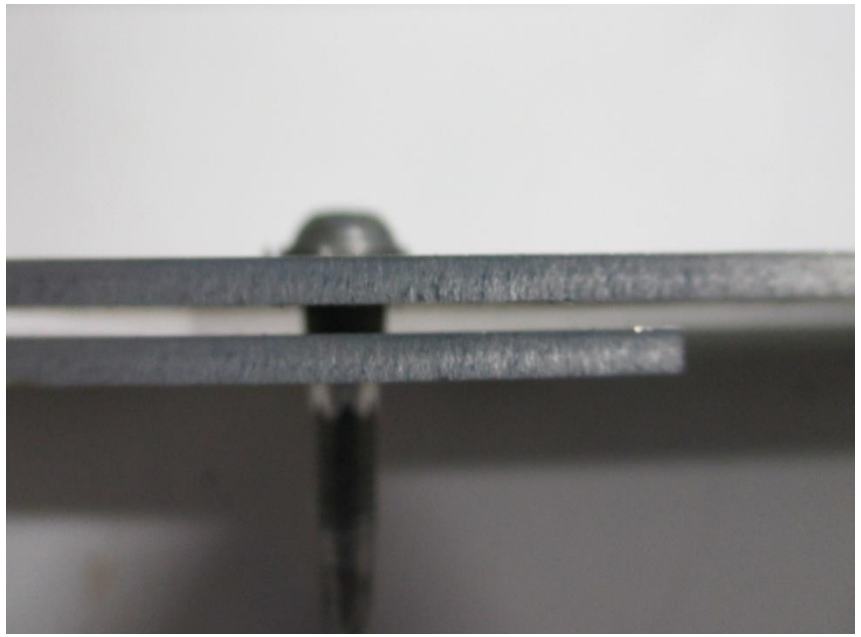


EJOT® Flow Drill Screws

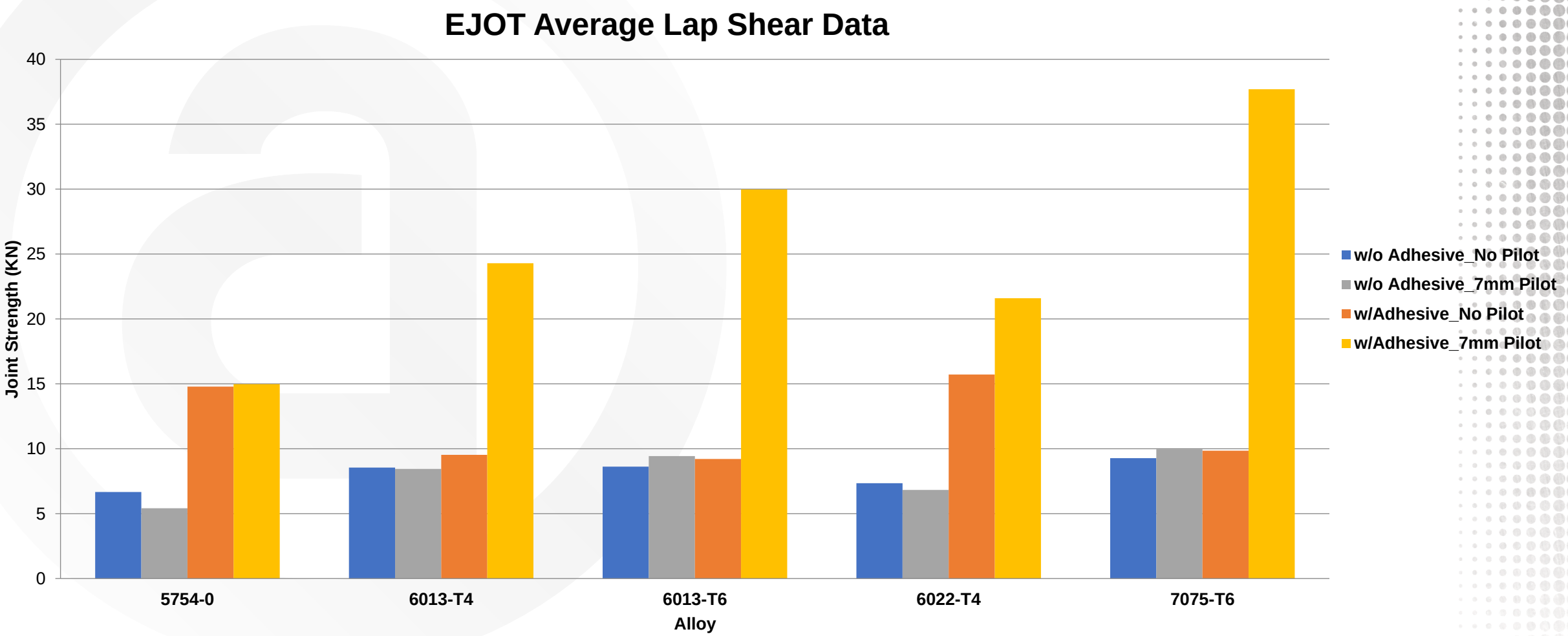
Lap Shear Joint with Pilot Hole



Lap Shear Joint w/o Pilot Hole

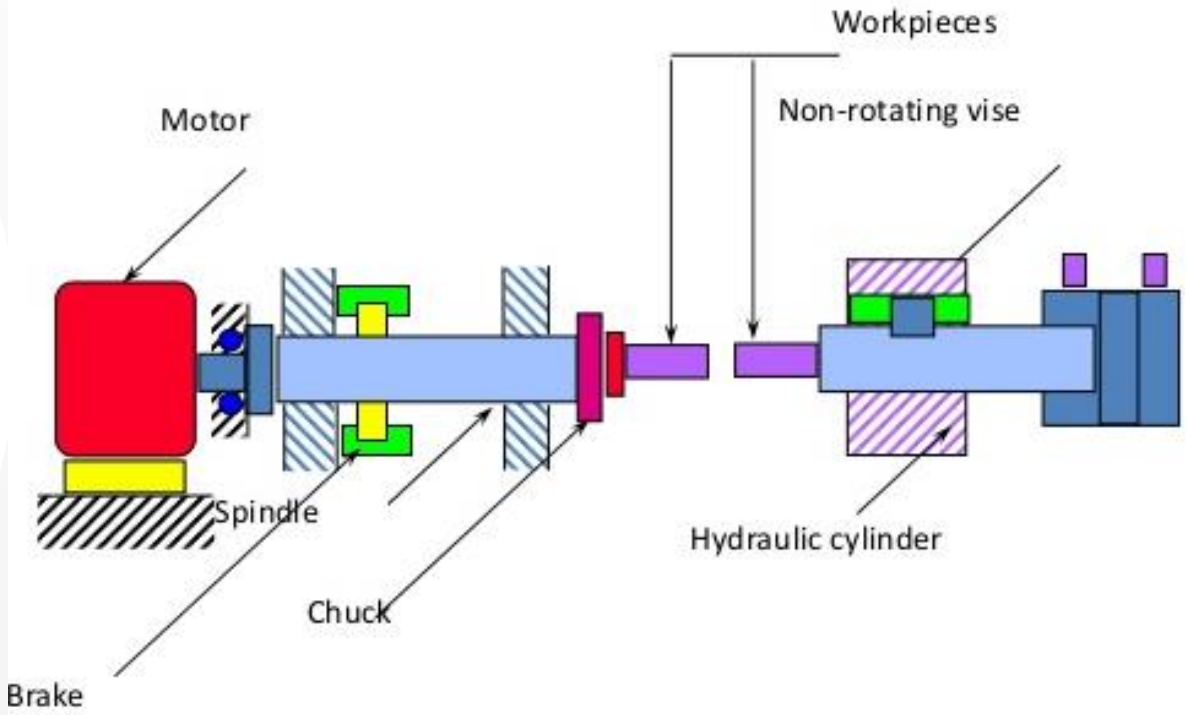


EJOT® Flow Drill Screws with 40mm Overlap

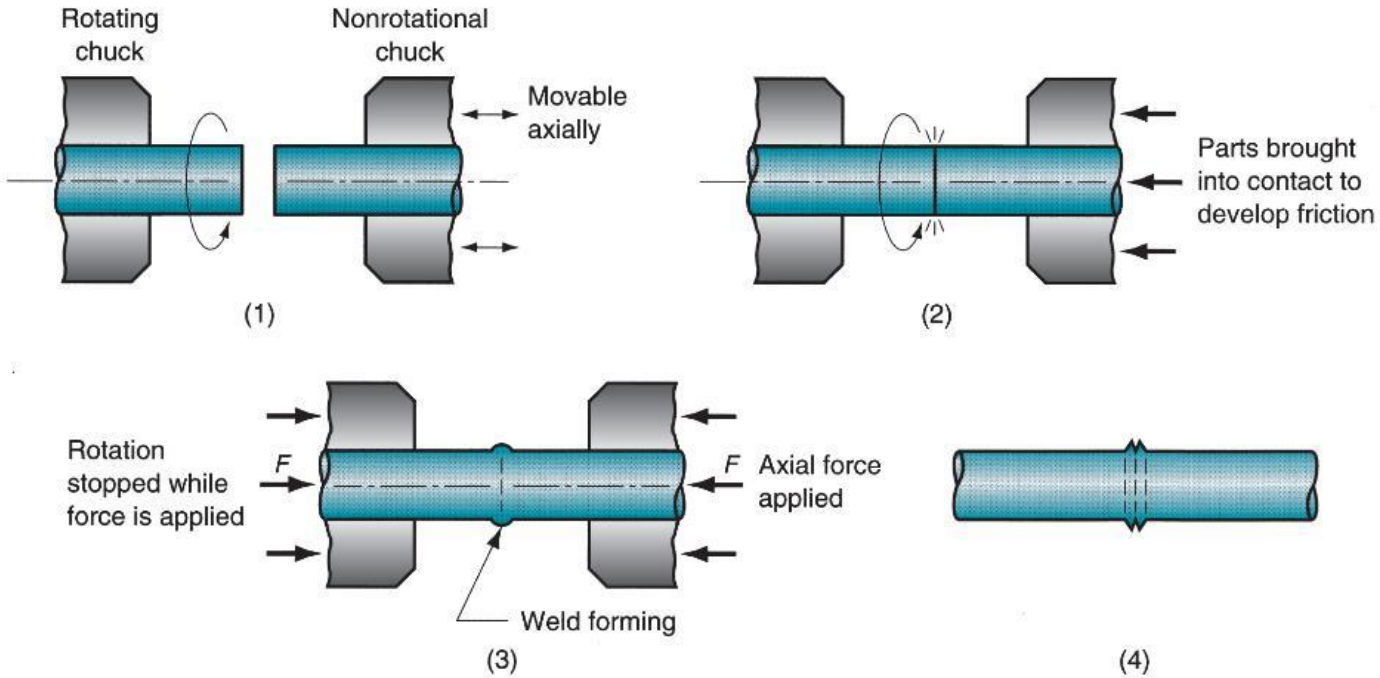


Friction Welding

- 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.

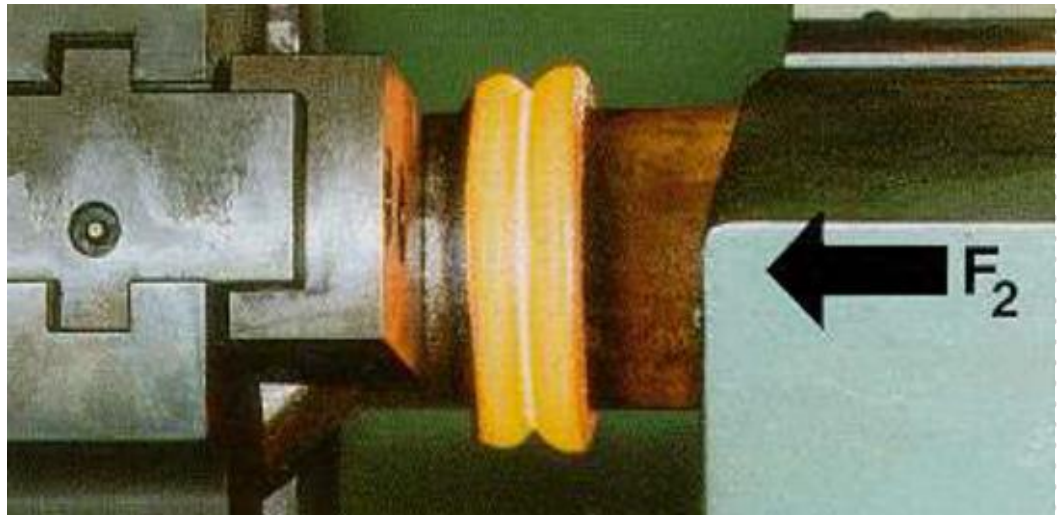


Friction Welding



- 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

Joining Technology/Material Combination	Al – Al	Al – Steel	Al – Mg	Al – Composite
Resistance Spot Welding	★			
Friction Stir Spot Welding	★	★		
Laser Welding/Laser Brazing	★	★		
Fasteners (SPR, FDS, Nails)	★	★	★	★
Clinching	★	★	★	
Adhesive Bonding	★	★	★	★

Source: CAR 2017

Questions?