Alcoa Innovation: transforming aluminum into better products!

ALCOA : innovation

With it's ties with the *Alcoa Technical Center*, Alcoa Innovation is supporting Quebec's industries in their projects using aluminum.

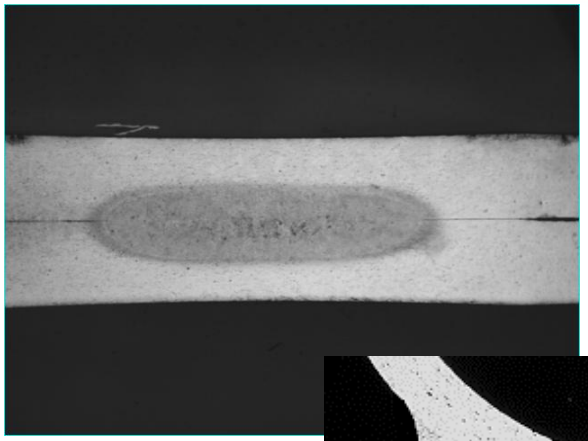
Common Joining Methods Used in Aluminum Structures

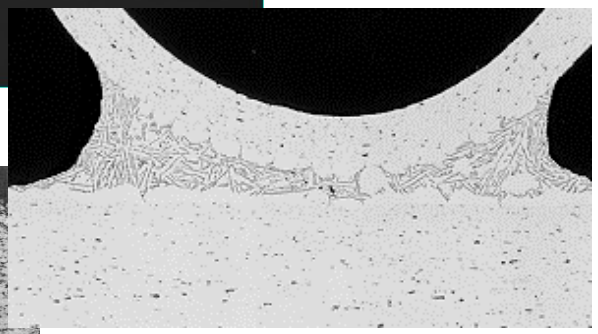
D.J. Spinella – Alcoa Technical Center

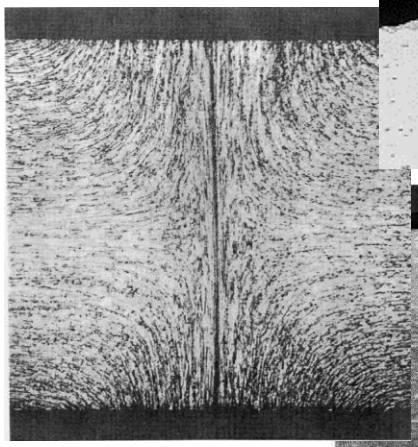
November 20, 2013

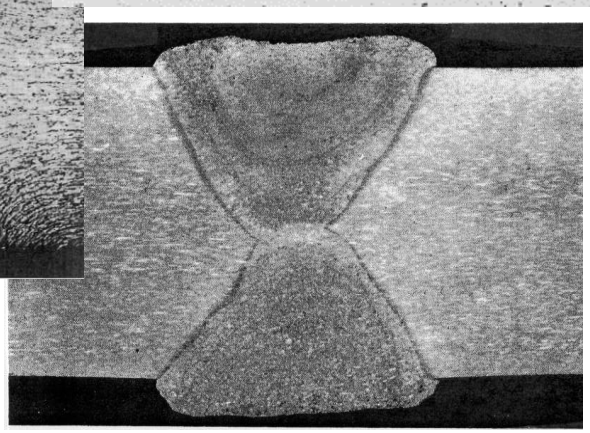
Common Joining Methods Used for Aluminum Structures Agenda

- Introduction
- Trends in Aluminum Structures
  - Design
  - Manufacturing Approaches
- Aluminum Joining Technology
  - Joining Technologies
  - Fusion-Based
  - Solid State
  - Mechanical / Adhesive
- Field Examples
- Questions









Alcoa Technical Center

- The Alcoa Technical Center is the world's largest light metals research and development center with a full range of lab capabilities, from bench-scale to full production-scale equipment.
- ATC employs approximately 600 scientists, engineers, technicians, and support personnel responsible for innovating the next generation of Alcoa products and services. Located on a 127-acre campus with an additional 2,019 acres of rolling countryside, it's Alcoa's largest research, development, and applied engineering laboratory. The facility has a diverse, multi-lingual workforce holding more than 98 doctorate and 166 master's degrees.

Product Manufacturing Technologies

- Manufacturing process development & technical support in forming, joining, machining, assembly, and prototyping
- Prototype manufacturing for Alcoa technology including demonstration and test articles
- Lifecycle support for multi-product & multi-material solutions
- Serves a broad array of markets
  - ➢Aerospace
  - ➢Automotive
  - ➢Commercial Transportation
  - ➢Rail and Marine
  - ➢Defense
  - ➢Consumer Electronics
  - ➢Oil and Gas

Product Manufacturing – Joining Technologies

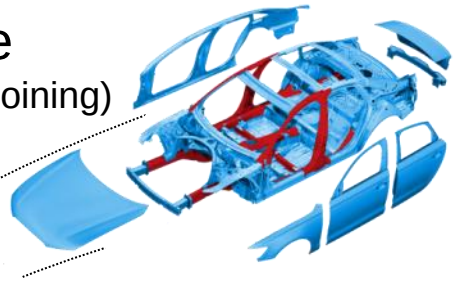
Develop and apply advanced joining technologies

- Arc and Fusion Welding
- Resistance Welding
- Solid-State Welding
- Mechanical Joining
- Adhesive Bonding

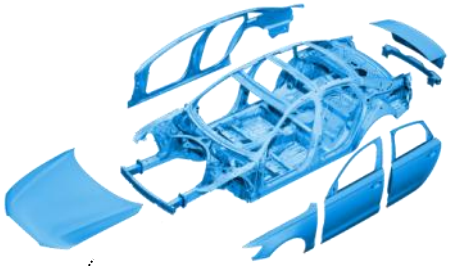
High Volume Auto Body Evolution

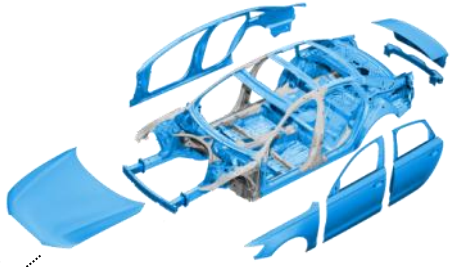
MPG Requirements

Aluminum Intensive Vehicle
(Strength & ductility for safety, Robust joining)

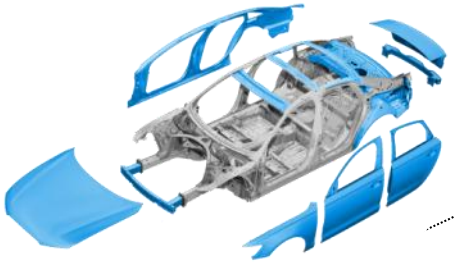


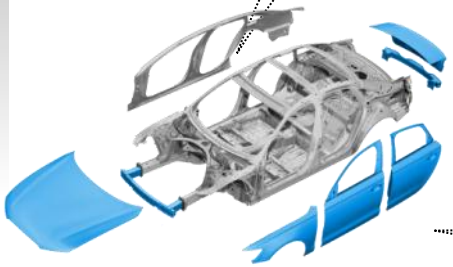
Multi-Material





Tailoring Products

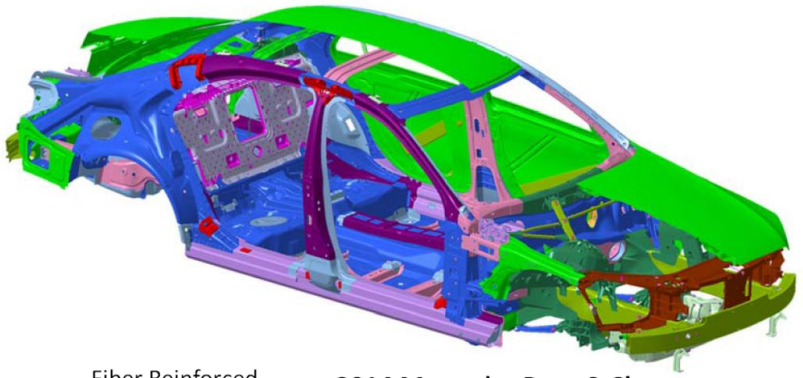




Steel & Aluminum Hybrid
(High scrap utilization, Steel to aluminum joining)

Aluminum Closures
(Increased formability for design/styling)

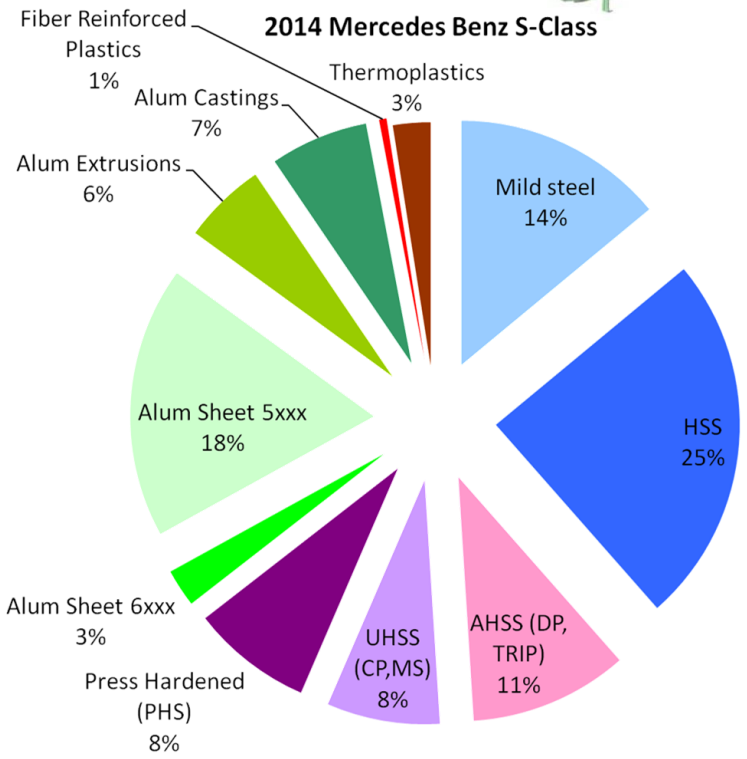
2014 Mercedes-Benz S-Class



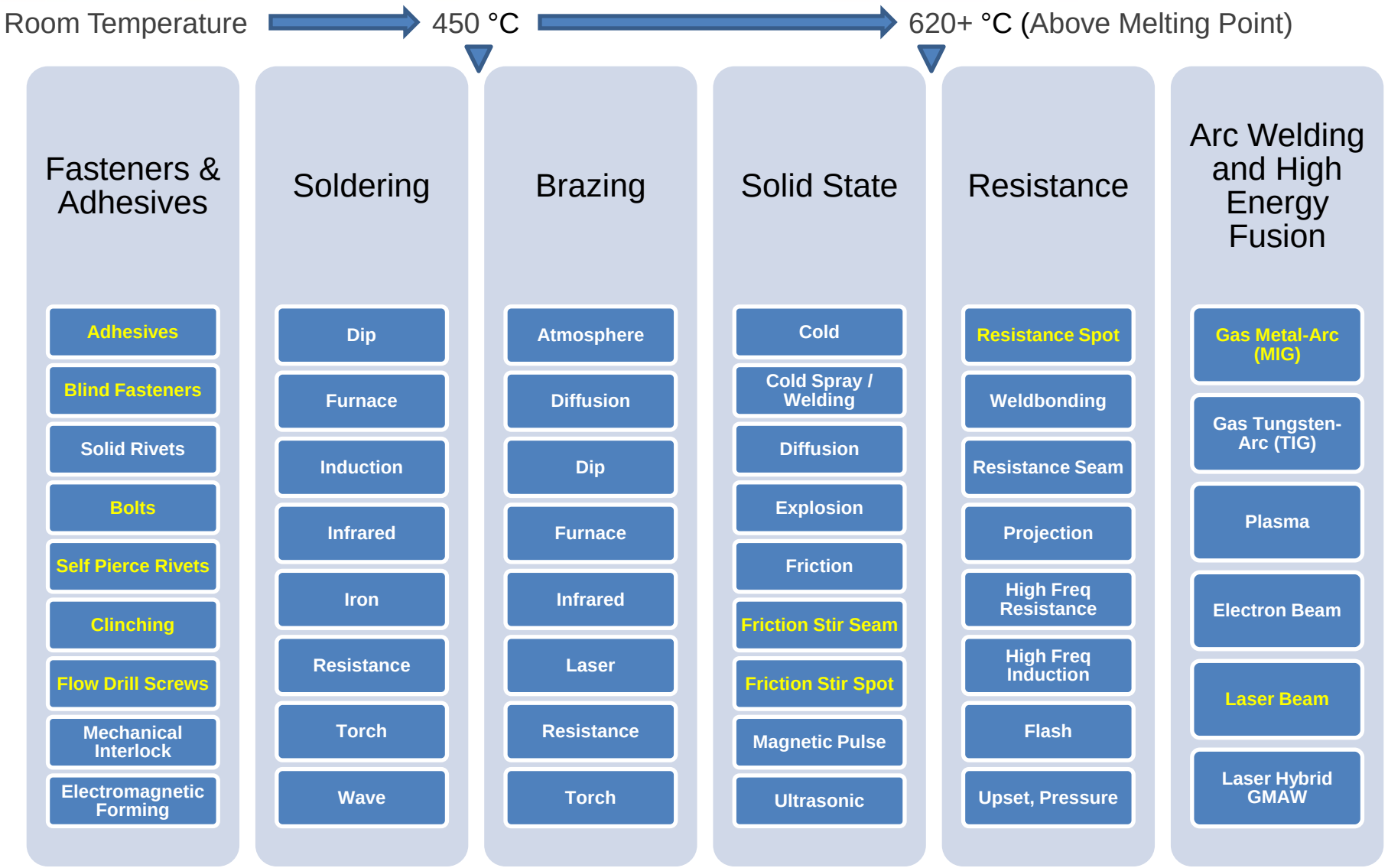
Aluminum roof, doors, hood, decklid, rear package shelf, frontend, front subframe

Saved 50 kg using aluminum over the steel body

2014 S-Class BIW Weight (kg)	362
Front Doors (2) (Kg)	21.8
Rear Doors (2) (Kg)	21.2
Hood (Kg)	12.7
Liftgate/Decklid (Kg)	6.7
Front Fenders (Kg)	3.3
Front Bumper/Other (kg)	7
Total (kg)	434.7

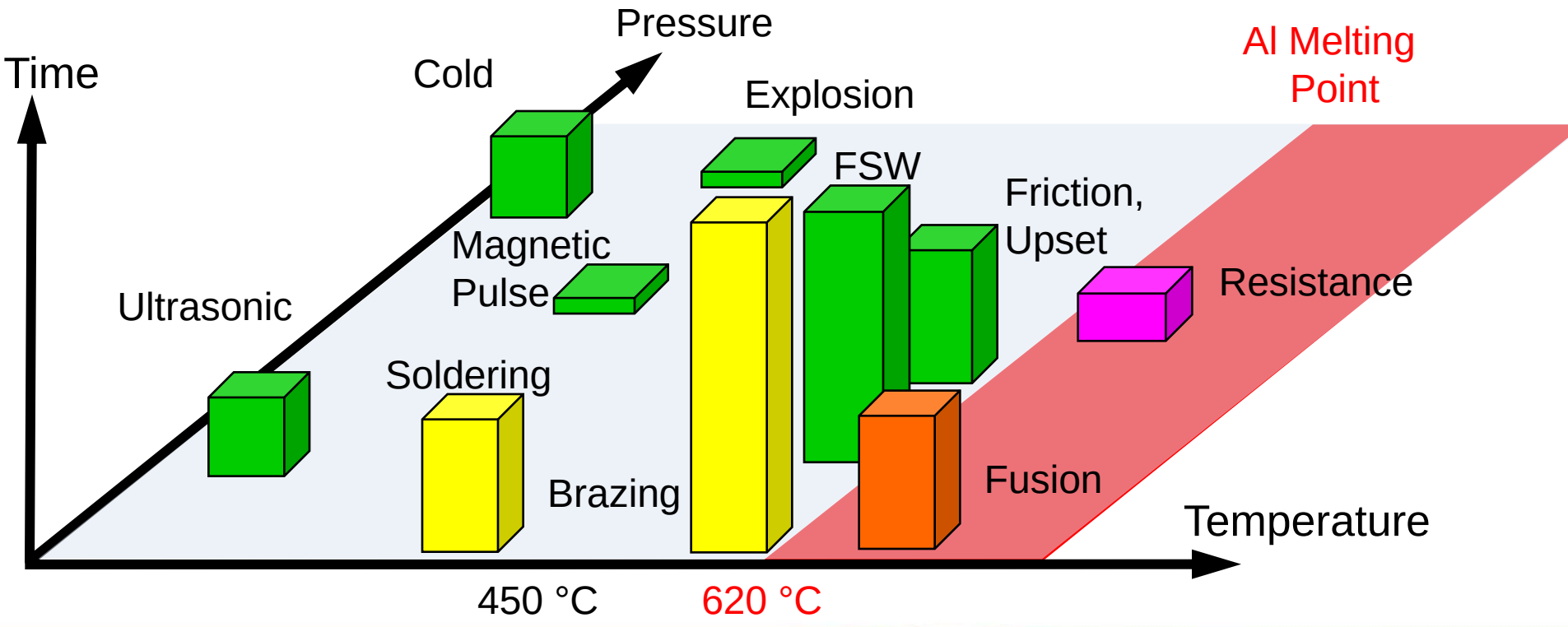


Aluminum Joining Technologies



Comparison of Various Joining Processes

- Many welding processes don't reach the melting point of the material
- Alloy of parent, heat & pressure profile, and filler metal determines
  - Mechanical Properties (tensile, yield, elongation, fatigue)
  - Physical Properties (corrosion, electrical resistivity, color match

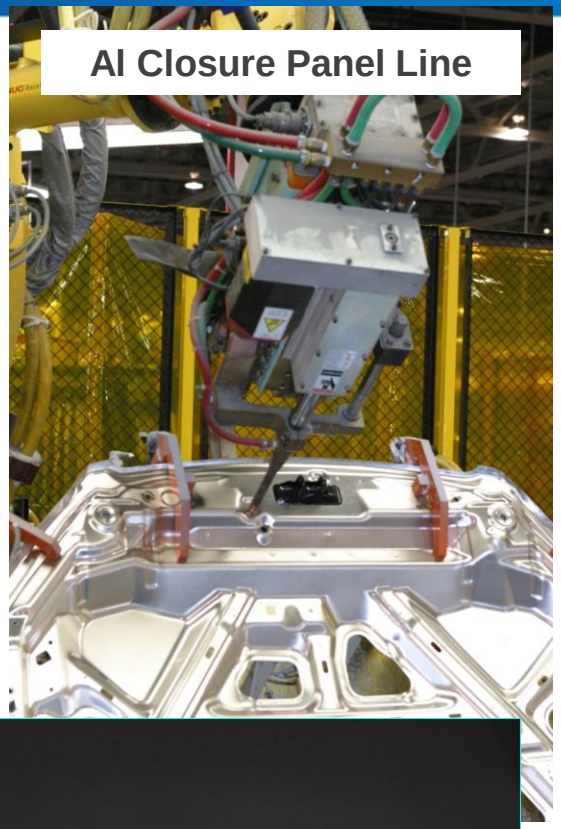


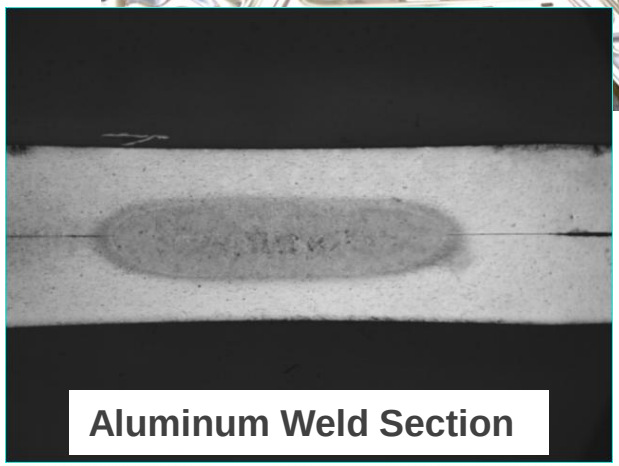
Competing Technologies vs. Robotic Steel RSW

	Mechanical Performance	Consumable Cost	Flexibility to Gauge Changes	Gun Accessibility	Aluminum to Steel Joining	High Strength Materials	Surface Pretreatments	Adhesive Compatible	Process Speed	Precision Alignment
Aluminum RSW	Lower	Low	Yes	2 Sided	No	Special Practices	No	Yes	Fast	Low
Self Pierce Rivet	Good	Yes	Limited	2 Sided	Yes	Special Practices	No	Yes	Fast	Low
EJOT, Flowdrill	Good	Yes	Yes	1 Sided	Yes - w/ pilot	Yes	No	Yes	Mod	Mod
Mechanical Clinch	Lower	Yes	Limited	2 Sided	Yes	Special Practices	No	Yes	Fast	Low
Adhesives	Good	Yes	Yes	1 Sided	Yes	Yes	Yes	Yes	Fast	Mod
Blind Fastener	Good	Yes	Yes	1 Sided	Yes	Yes	No	Yes	Mod	Mod
Ultrasonic	Lower	Low	Limited	2 Sided	Limited	Yes	No	Limited	Mod	Mod
Friction Stir Spot	Lower	Low	Limited	2 Sided	Yes	Yes	No	Limited	Mod	High
	Improvement		Baseline		Lower		Limited			

Resistance Spot Welding - RSW

- Aluminum sheet is spot welded in several high volume closure applications
- Structural applications have been limited to only a few niche vehicles
- Issues versus steel RSW
  1. *Process consistency (it's all about surface)*
  2. Requires higher capacity welding transformers (2.5X weld current)
  3. Questions on process robustness to production conditions (electrode angularity, gaps, etc.)
  4. QA and NDE procedures are not validated
  5. Lubricant and adhesive impact on weld quality
- Advantages
  - Equipment designed to weld aluminum can easily process steel
  - Leverages steel RSW infrastructure & logistics





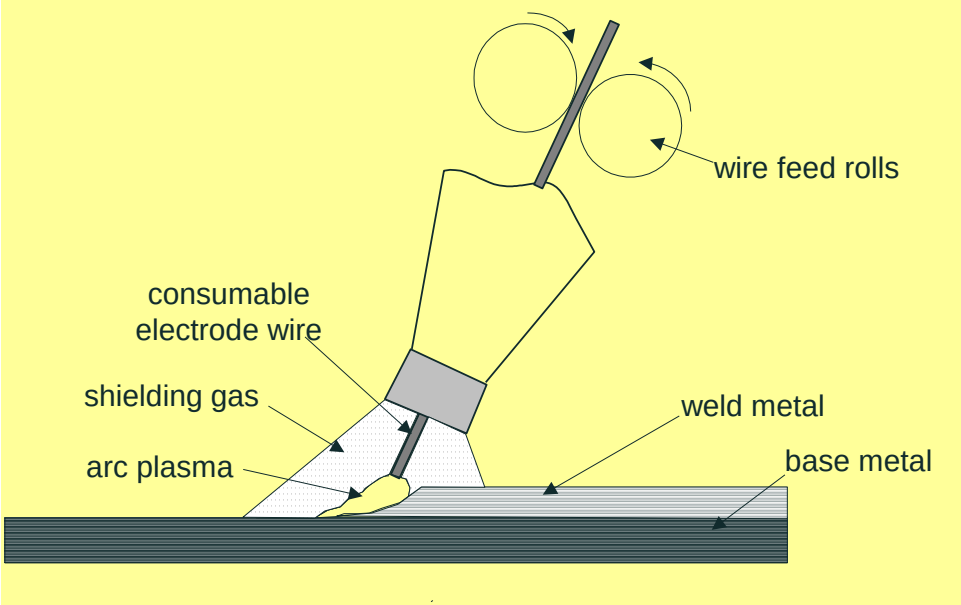
Gas Metal Arc Welding - GMAW

Advantages

- Manual or automatic
- Suitable for welding most joint types and positions
- Applicable to joining various thicknesses (≥1.5 mm) & combinations
- Travel speeds - 0.5 to1.5 m/min

Disadvantages

- Sensitive to variations in joint gaps & lateral edges relative to welding torch
- More prone to formation of weld porosity than GTAW
- Not as “fine” to control as GTAW
- May require parts to be cleaned of lubricants and contaminants



www.lincolnelectric.com

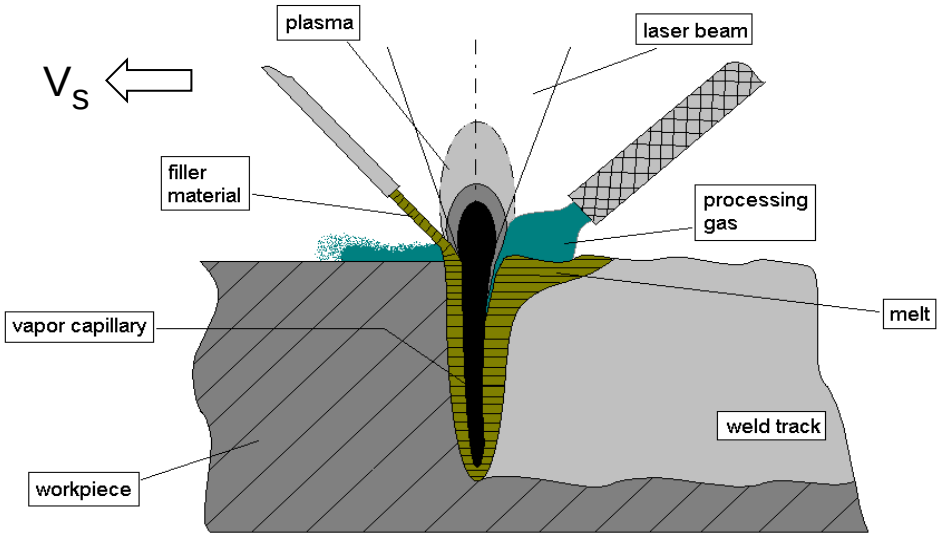
Laser Beam Welding – Advantages and Disadvantages

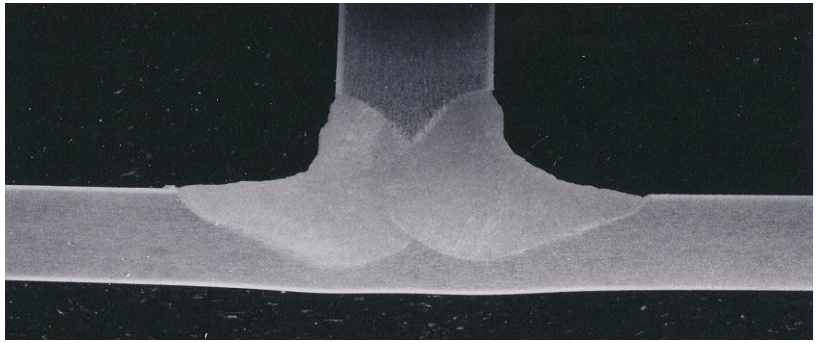
Advantages

- Higher welding speeds of travel on thin sections
- High penetration/width ratio of welc
- Precise heat input yields narrower weld beads, heat-affected zones & distortion
- Lap-Penetration &Square-Butt joint
- Continuous or stitch welding mode
- Robot or gantry systems
- Beam-sharing between stations

Disadvantages

- Certain alloys will require a filler alloy (hybrid GMAW or cold feed)
- Joint fitup and precision
- Capital costs





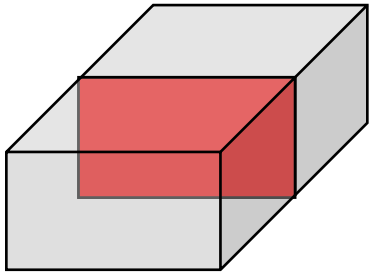
Laser Beam Fillet Weld

Solid-State Welding – Key Characteristics

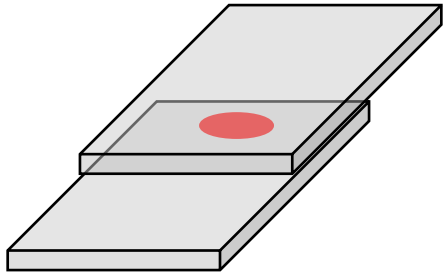
- Surface oxides must be removed / displaced / dispersed so that parent metals come into direct contact
- Combinations of heat, pressure & time
- Deformation may be present
  - Plasticized materials displace oxides, pressure allows intimate contact resulting in metallurgical bonding
- Temperatures below material's melting point
  - Allows dissimilar material combinations (AL to ST, AL to CU) since intermetallics are not generated
  - *If temperatures above melting*, molten metals and intermetallics must be expelled for good properties.

Solid-State Joint Configurations

Butt



Lap (Spot or Seam)



Cold	Upset Resistance	Friction	Friction Stir	Magnetic Pulse	Ultrasonic	Explosion
•Area <0.5in^2 •Single Weld •Various shapes	•Area <30in^2 •Single or Continuous •Various shapes	•Area <60in^2 •Single Weld •Round shapes	•Area <2in^2 •Single or Continuous •Various shapes	•Diam <0.25in •Single or Continuous •Various shapes	•Diam <0.25in •Single or Continuous •Various shapes	•Area >100ft^2 •Single Weld •Various shapes

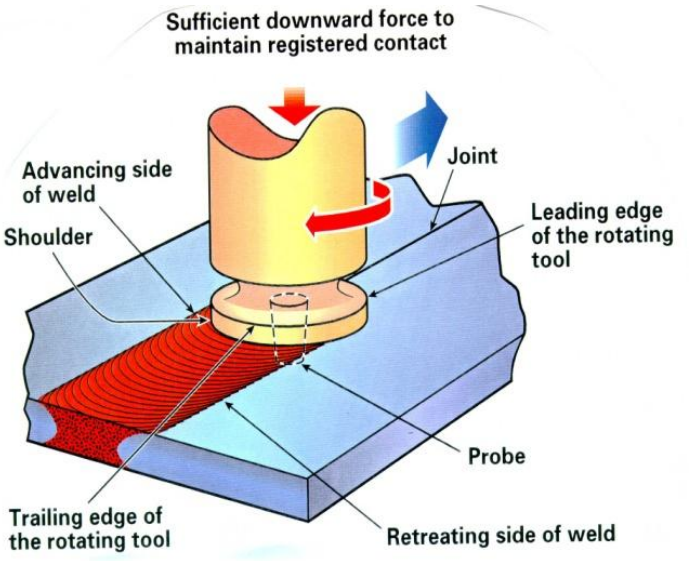
Friction Stir Welding Process

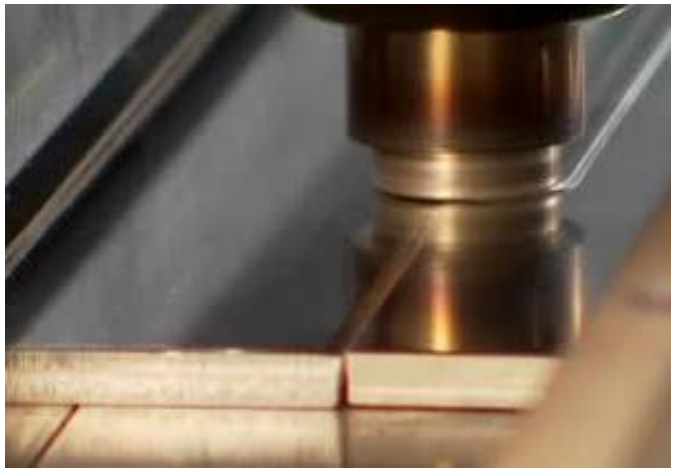
Advantages

- Good mechanical properties
- Minimal weld induced distortion
- Full or partial penetration from one side
- Square butt & lap-penetration type joints
- High quality welds involving fewer repairs and rejects
- No filler alloy addition & shielding gas
- Very simple to operate and maintain
- Welds aluminum alloys normally considered non-fusion weldable (e.g., 7050, 7075 and 8090)

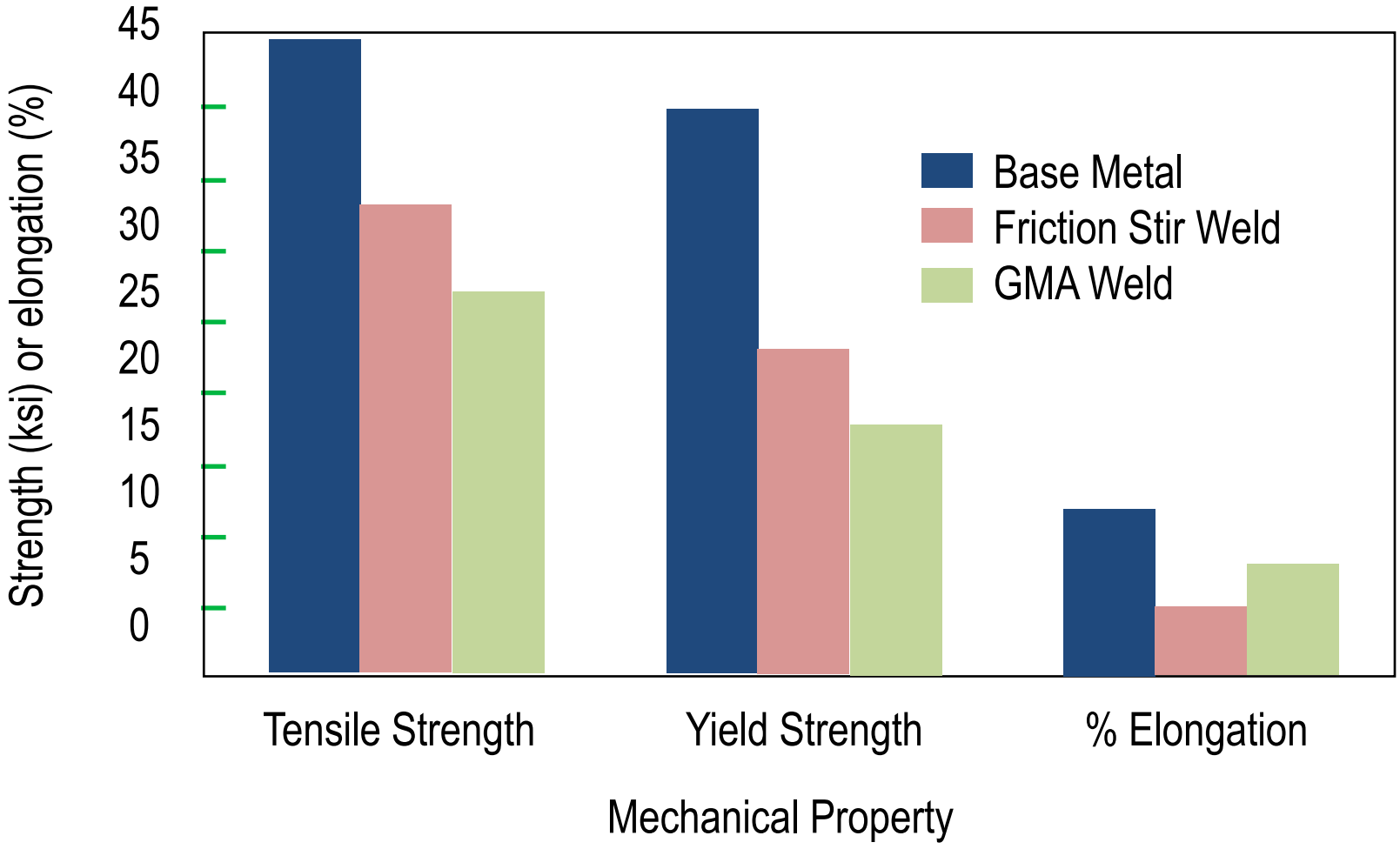
Disadvantages

- Requires good fitup and clamping systems
- Supply chain / integrators limited





FSW versus GMAW Property Comparison: 6061-T6



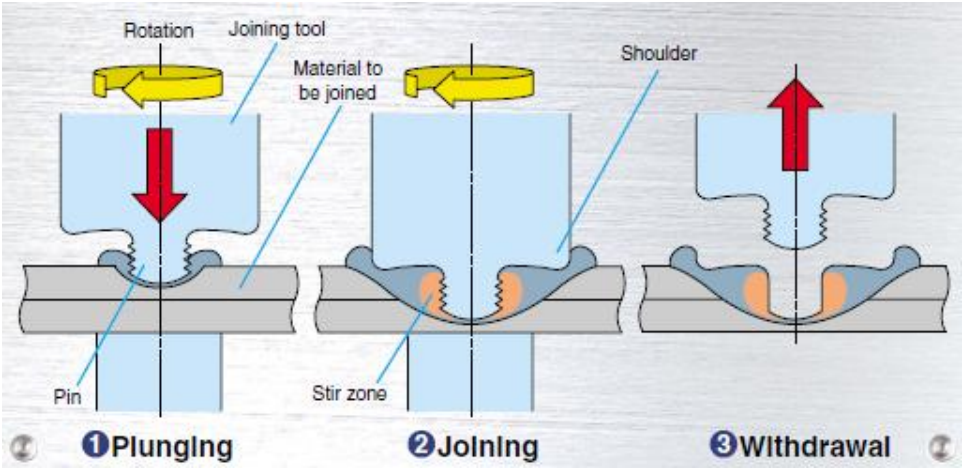
Friction Stir Spot Welding

Advantages

- Replaces RSW and mechanical fastening joints
- Minimal weld induced distortion
- Stitch and refill variants
- Low consumable & infrastructure costs (low electricity, no chilling water)
- Welds aluminum alloys normally considered non-fusion weldable (e.g., 7050, 7075 and 8090)

Disadvantages

- Cycle time for thick stackups
- Switching between different stackups and material combinations



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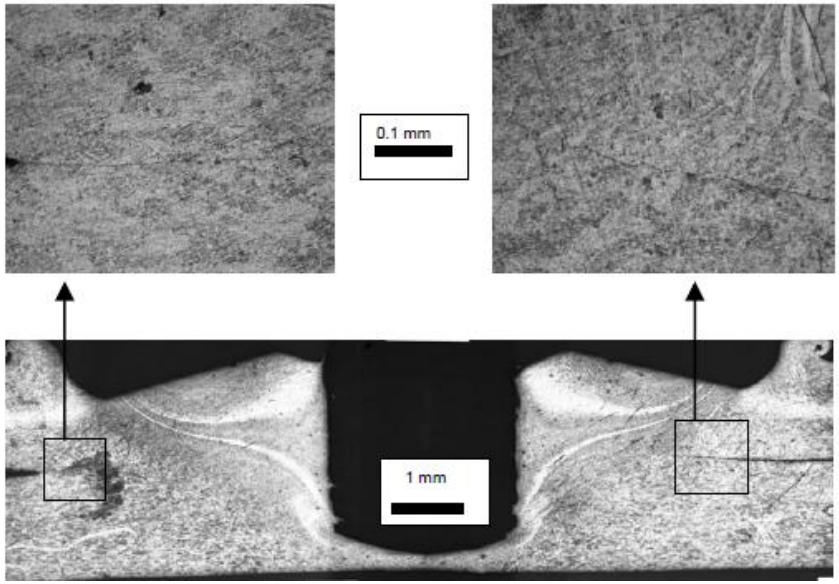
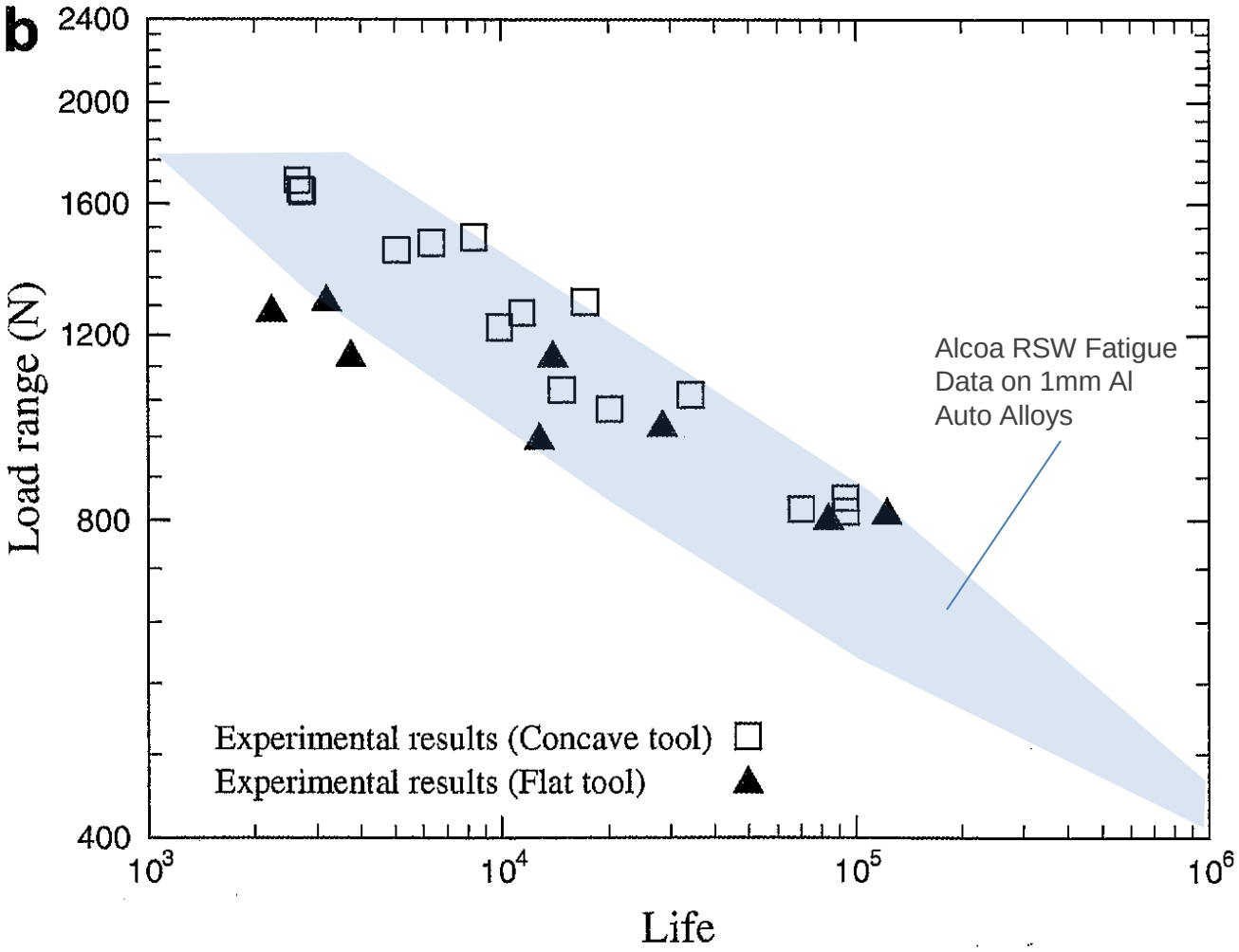


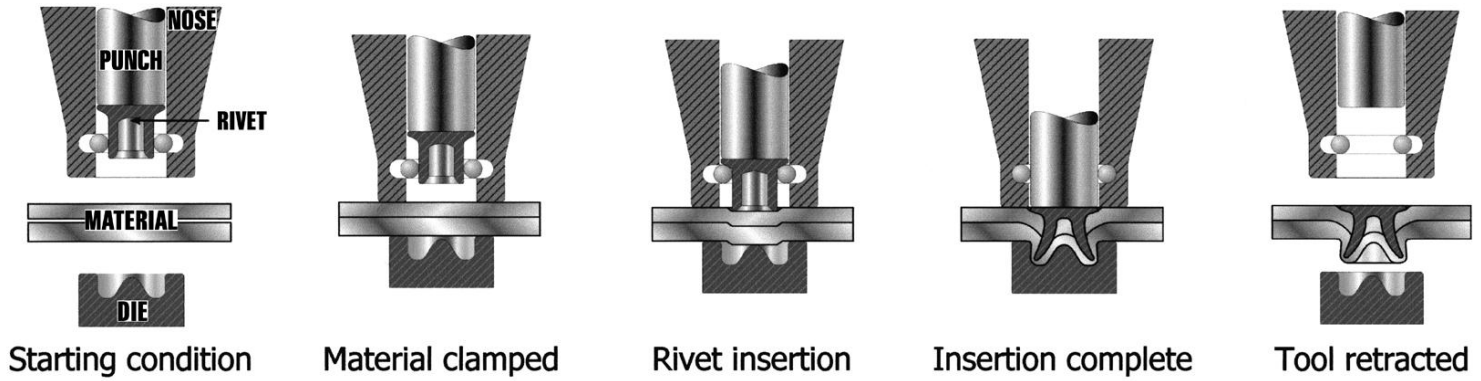
Arul et. al., "Effects of Surface Treatment (Lubricant) on Spot Friction Welded Joints Made of 6111-T4 Aluminum Sheets", SAE Paper 2007-01-1706

Friction Spot Welding Fatigue Performance – 0.94mm 6111-T4



Lin et.al., "Failure modes and fatigue life estimations of spot friction welds in lap-shear specimens of aluminum 6111-T4. Part 2: Welds made by a flat tool", International Journal of Fatigue, Vol. 30 (2008) 90-105

Mechanical Fastening: SPR – Self-Piercing Rivet



Factors for SPR Joint Design

- Total Stack-Up Thickness
  - Determines rivet length
- Flange or Overlap Width
- Edge Distance
- Tool Clearance
- Materials being Joined
  - Aluminum
  - Steel
  - Multi-Materials (Hybrids)

Stack-up / Orientation

- Softer (top) to Harder (bottom)
- Thick to thin, thin should be no less than 1/3t of the thicker

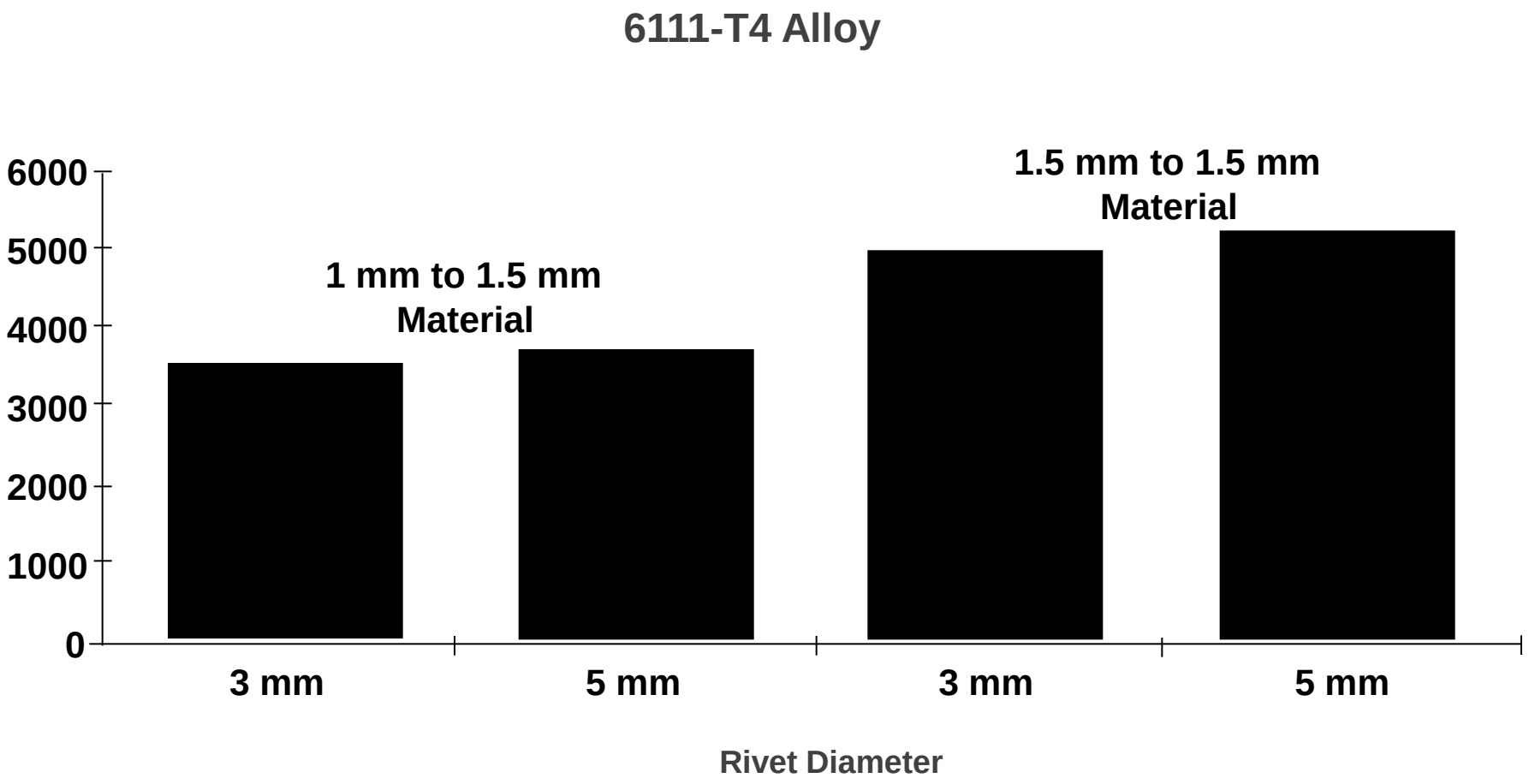
Rivet Diameter

- 3 mm or 5 mm
  - Joint strength
  - Robustness of joint
  - Access

Rivet Length

- 3 mm rivet, 1.5 - 3.0 mm > than stack
- 5 mm rivet, 2.0 - 4.0 mm > than stack

Mechanical Fastening: SPR – Self-Piercing Rivet



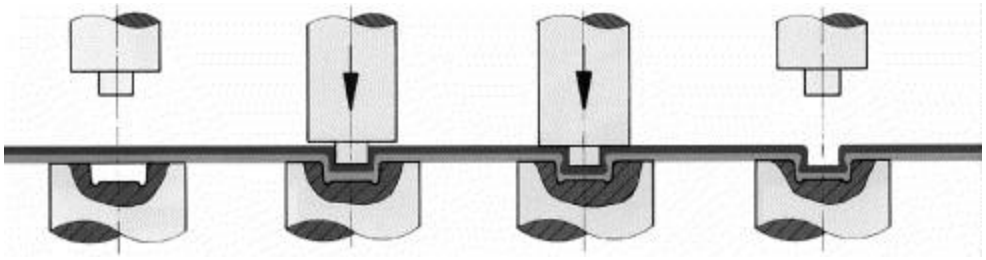
Mechanical Fastening: EJOT® Flow Drill Screws

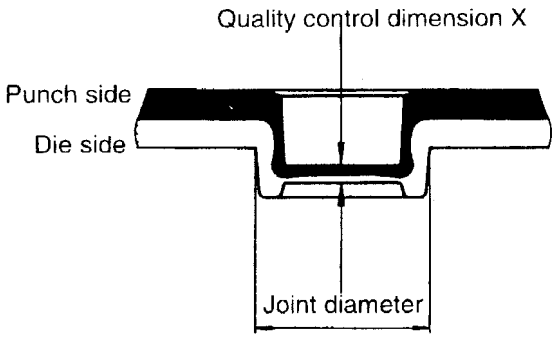
1. FLOW DRILLING SCREW (FDS) is applied to surface with medium thrust and spindle rotation.
2. As friction and heat increases, the surface plasticizes and begins to “flow“.
3. Material begins to form the extended threading are behind the application.
4. As the flow phase ends the ‘thread rolling‘ phase begins with lower RPM on the spindle.
5. The screw now begins to act like a normal fastener and is driven to a torque.
6. The fastener is seated as it would be in any normal toque strategy. As the materials cool it also contacts around the threads for added joint integrity.

Weber Screw Driving Systems

Mechanical Fastening: TOX Mechanical Clinch

TOX Clinching Process





Material Stack-up / Orientation

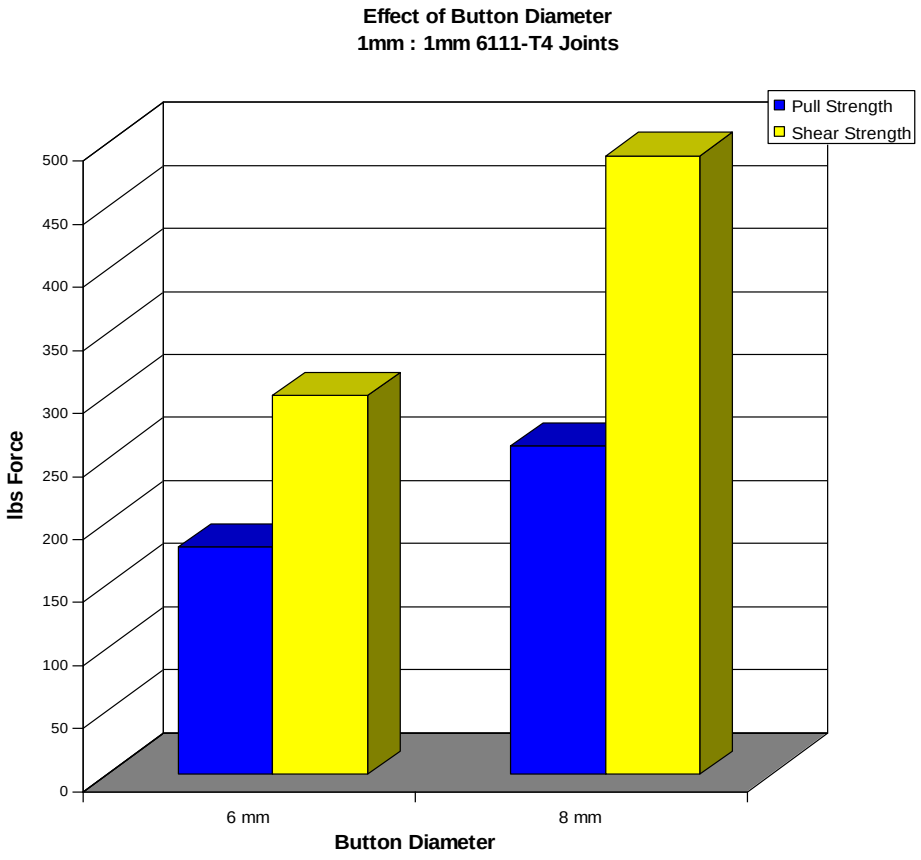
- Preferable to have thicker or harder material on punch side
- Minimum single sheet thickness of 0.3 mm (depend on TOX diameter)
- Maximum combine thickness is 8 mm (depend on TOX diameter)
- Total stack-up of 2 to 4 layers possible

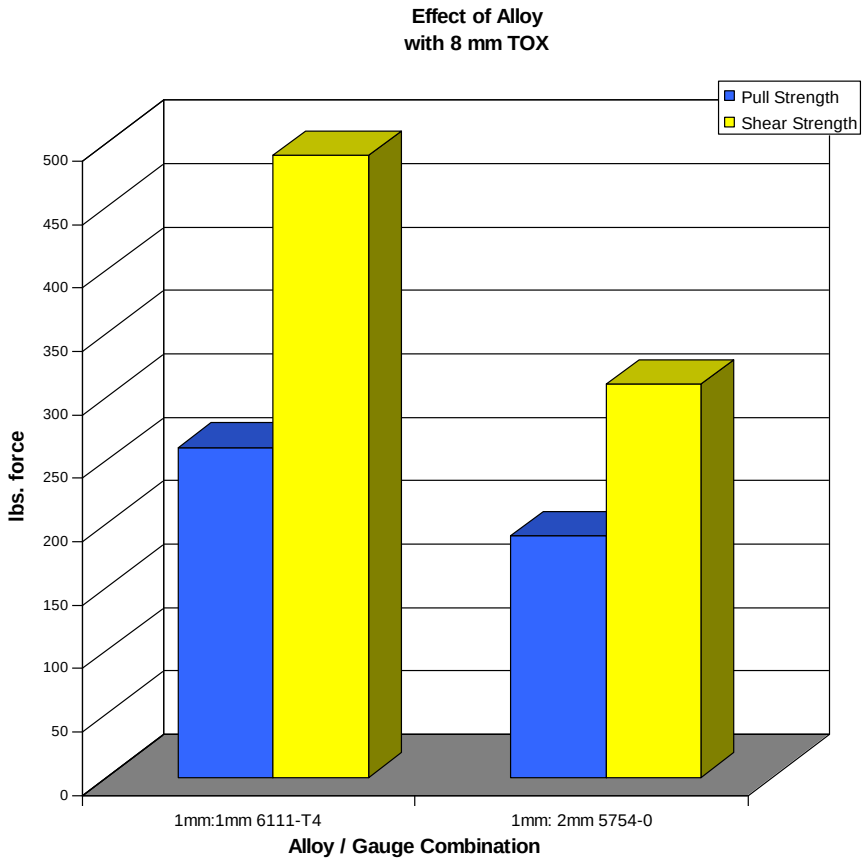
TOX diameters

- Available in 3, 4, 5, 6, 8, 10, and 12 mm button diameters

Mechanical Fastening: TOX Mechanical Clinch

TOX Joint Strength

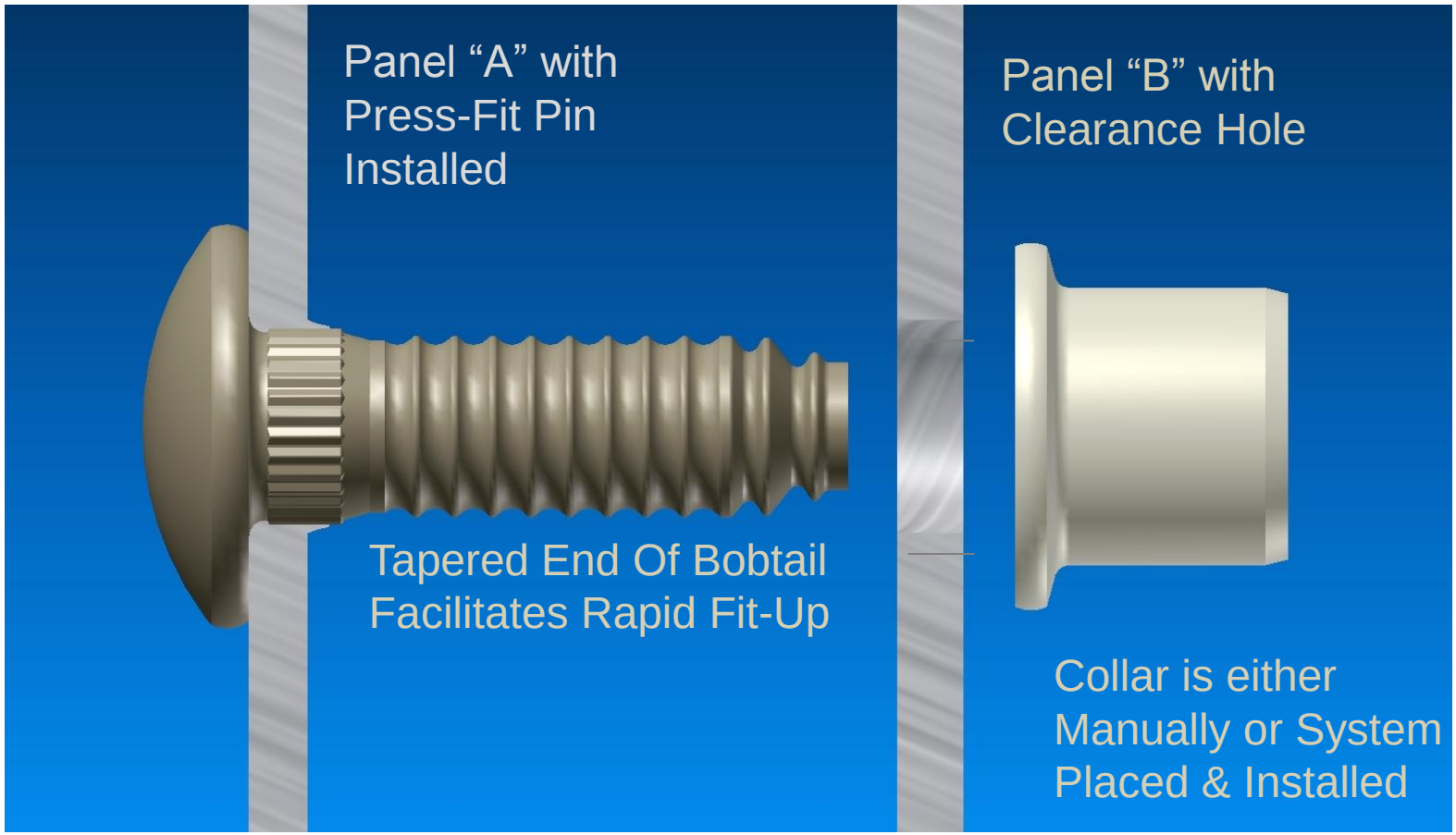




Bobtail Clinch Stud

Alcoa Fastening Systems

ALCOA



For high strength or dissimilar material joining to replace RSW, SPR & FDS in 2,4, & 6mm stack-ups.

http://www.afsglobal.net/

Bobtail Lock Bolt
Features and Benefits

Alcoa Fastening Systems

ALCOA

Features	Benefits
■ Vibration Proof	• Maintenance free • Longer equipment uptime
■ Ergonomic installation	• Fast fit-up • No tooling vibration or shock load • Quiet
■ Shallow, low notch factor bolt thread	• High fatigue strength • Absorbs high spike loads
■ Grade 8 and Class 10.9 strength	• Easy upgrade from conventional nuts and bolts
■ Directly Tensioned without Torque	• Delivers high and precise clamp load, ± 6% max variation

http://www.afsglobal.net/

Huck 360™ Performance Objectives

Alcoa Fastening Systems

ALCOA

- Develop a very high strength bolting system for farm and military equipment
- Fast installation and removal with conventional tools
- Must stay tight under severe vibration loading
- Must have superior fatigue strength to hold up against high spike loads

http://www.afsglobal.net/

Huck 360™ Features and Benefits

Alcoa Fastening Systems

ALCOA

Features	Benefits
■ Vibration Proof	• Maintenance free • Longer equipment uptime
■ Free running thread	• Fast fit-up • No coating damage • Easy removal • Field Serviceable
■ Shallow, low notch factor bolt thread	• High fatigue strength • Absorbs high spike loads
■ Grade 8 and Class 10.9 strength	• Easy upgrade from conventional nuts and bolts
■ Removable and reusable	• Installed with Standard Tooling • Field Serviceability

http://www.afsglobal.net/

Huck 360™ Bolt Comparison

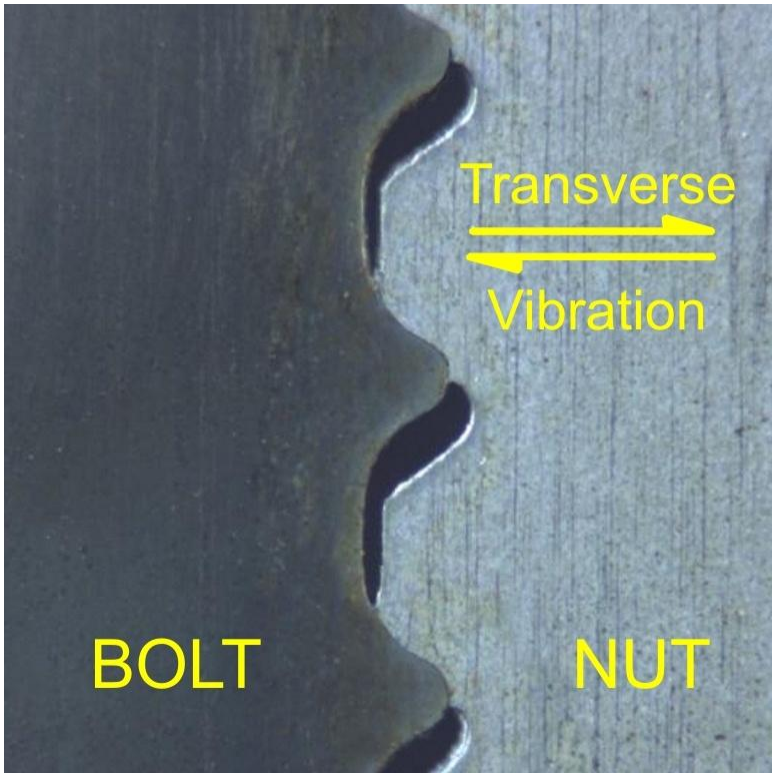
Alcoa Fastening Systems

ALCOA

Features	Standard Bolt	Traditional Lock Bolt	2008 Bobtail®	2009 Huck 360™
				
Clamp Load	High	High	High	High
Clamp Variation	±30%	±6%	±6%	±20%
Removable	Yes	Semi-permanent	Semi-permanent	Yes
16 mm Tool Weight	< 10 lbs.	20 lbs.	< 10 lbs.	< 10 lbs.
Vibration Resistance	Low	High	High	High

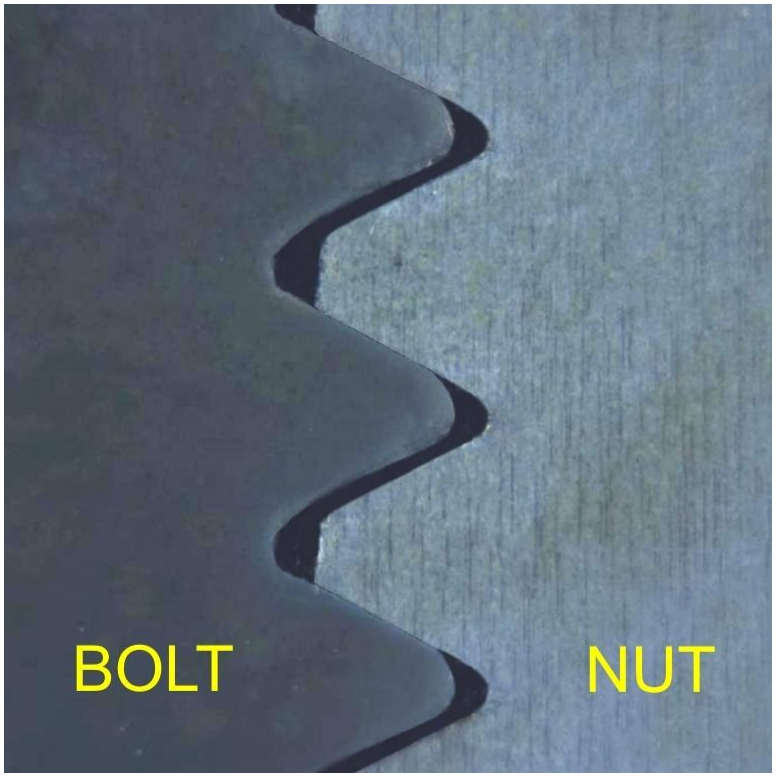
http://www.afsglobal.net/

Huck 360™



Thread Flanks are Locked.
Nut cannot move relative to bolt.

Conventional Thread



Thread Flanks can slide.
Nut can move relative to bolt.

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Production Blind Riveting Technology for Truck & Trailer - HUCK-LOK

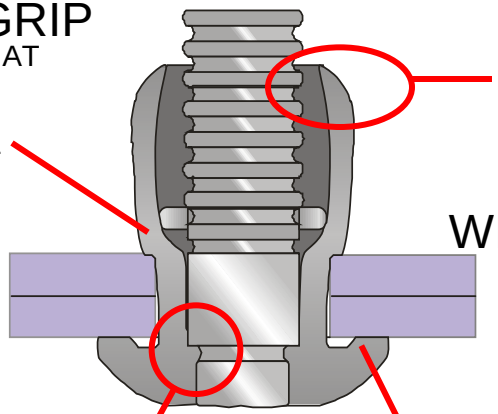
Alcoa Fastening Systems

ALCOA

MINIMUM GRIP

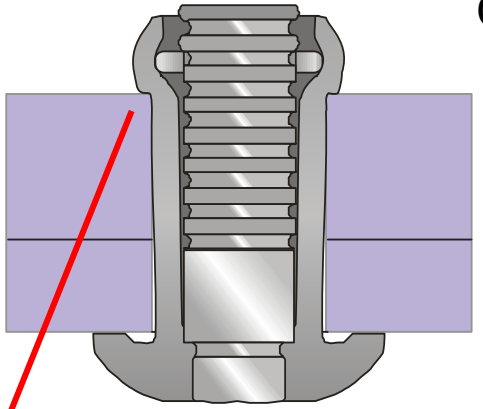
SHEAR RING AT SHEET LINE PROVIDES CONSISTENT CLAMP

END ANNEALED SECTION



WIDE GRIP RANGE

MAXIMUM GRIP



FLUSH INSTALLATION

FLUSH PINBREAK ELIMINATES NEED FOR GRINDING OR FILING

PATENTED SOLID LOCK CIRCLE ENSURES MAXIMUM STRENGTH AND RESISTANCE TO VIBRATION

BLIND SIDE FOOTPRINT GIVES FASTENER HIGH PULLOUT STRENGH

DIAMETERS: 3/16ths – 1/4”

MATERIAL: STEEL (ALUMINUM AND STAINLESS STEEL IN DEVELOPMENT)

http://www.afsglobal.net/

Automated Drilling & Riveting for Blind Applications

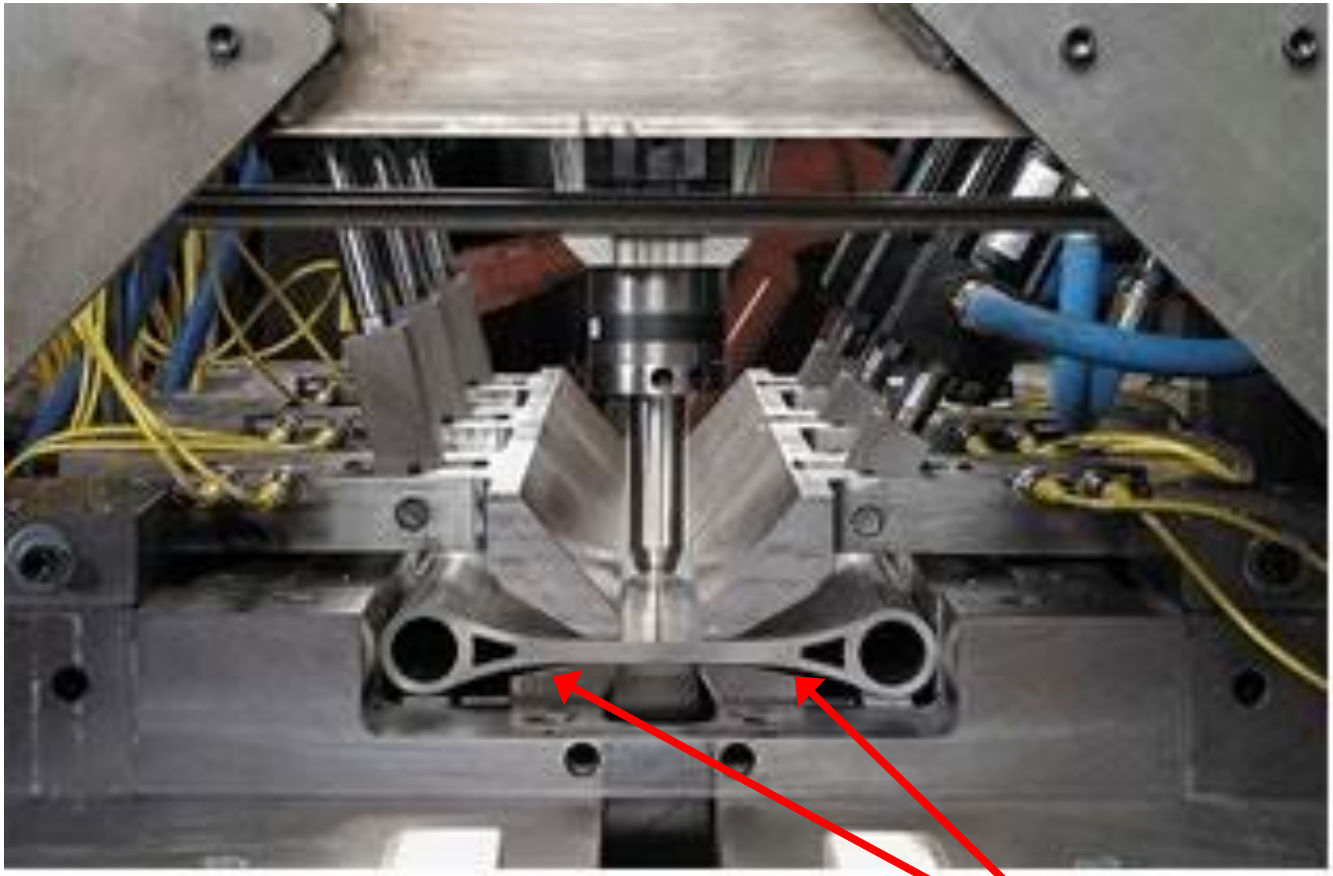
Alcoa Fastening Systems

ALCOA

http://www.afsglobal.net/

Aluminum Joining Applications

Friction Stir Welded Suspension Link for Lincoln Town Car



Jaguar Land Rover Aluminum Vehicles

2013 Jaguar XJ
Aluminum since 2003

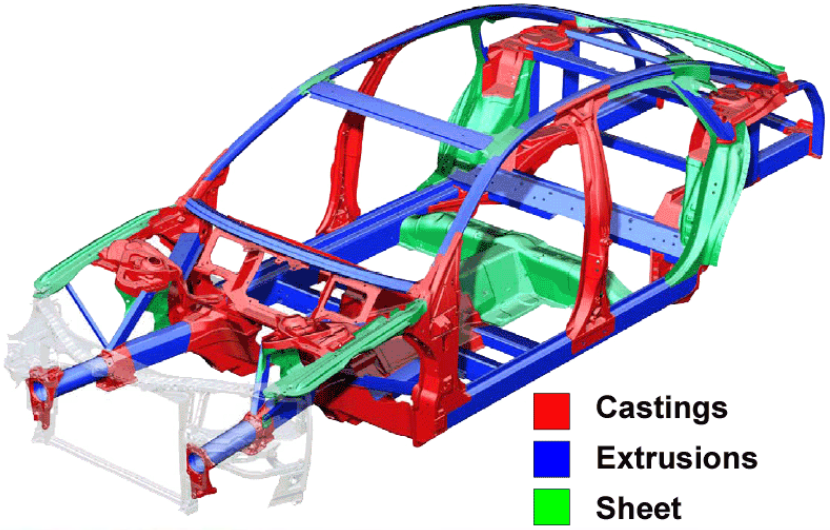
2013 Range Rover

2013 Jaguar XK
Aluminum since 2006

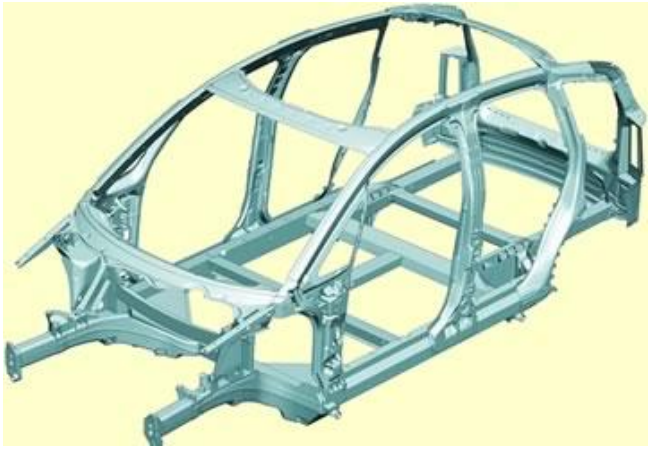
2013 Jaguar F Type

2nd Generation Audi A8

- Reduced components by 40% and assembly costs
- Major parts consolidation attributed to large castings
- More interior space than its predecessor
- Faster than its predecessor
- Joining Technologies
  - Laser-hybrid welding
  - 65 feet of laser welding
  - SPR



Audi A2



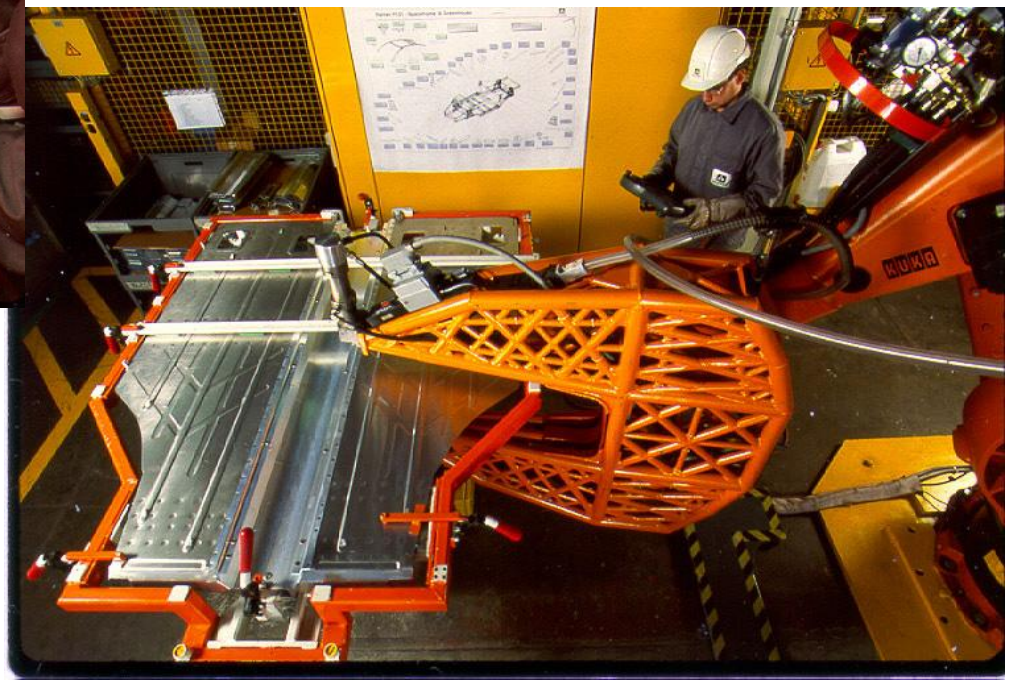
"Aluminum Now", Aluminum Association, November/December 2001

- 30 meters of laser welds

Aluminum Association's Aluminum Welding Seminar, 2003

Ferrari 360 Modena

- AL sheet, extrusions, and castings
- SPR, arc-welding



Plymouth Prowler

- AL sheet, extrusions, and castings
- SPR, arc-welding

Automotive Applications – Closures and Structures

Resistance Spot Welding

www.ford.com

Ford Explorer
AL hood and fenders

www.nissanusa.com

Nissan Altima
AL hood and decklid

Self Pierce Riveting

www.chrysler.com

Plymouth Prowler
SPR body and panels

Friction Stir Spot Weld

www.media.mazda.com

Huck 360™s are being used in a wide range of applications

Alcoa Fastening Systems

ALCOA

Track Diamonds

Temporary Frame connection

Mining – Spring Base Plate Discharge Chute Liner

RV Frames

More Huck 360™ Applications

Alcoa Fastening Systems

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Pig Dehairer – Scraper Paddles

Street Sweeper – Shaker Screen

Truck Frame

Appliance connections

Solar Applications

Alcoa Fastening Systems

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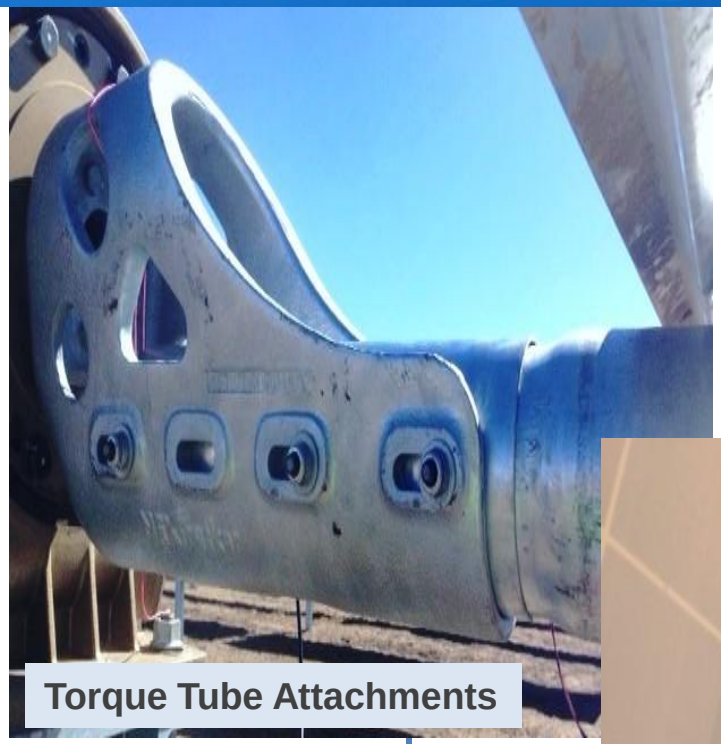
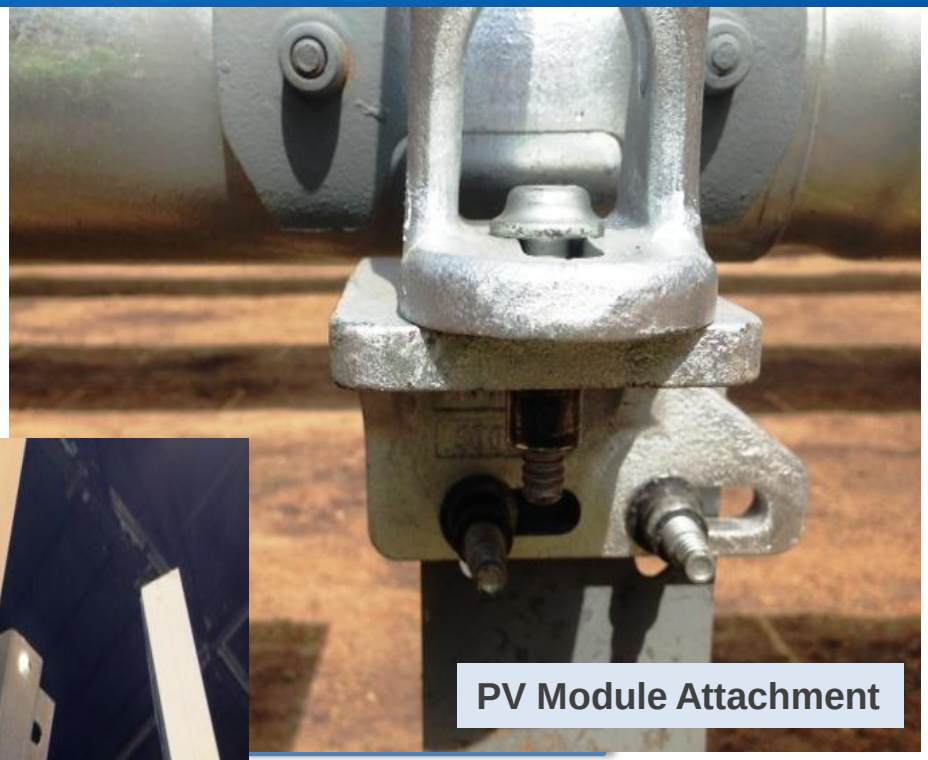


Torque Tube Attachments



PV Module Attachment

I-Beam to Frame Attachment

Acknowledgements

The presenter would like to thank the following individuals for supplying information and slides for this presentation: Bob Corbett of Alcoa Fastening Systems; Dan Bergstrom, Russ Long, and Kyle Williams of the Alcoa Technical Center

Advancing each generation.