Innovative methods for joining of mixed light-weight material combinations

JODIMACO - Joining of Difficult Material Combinations

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Manufacturing R&D Clusters

JODIMACO
Joining of Difficult Material Combinations

- Scope and objective

  Achieve strategies for joining of structural components combining UHSS and die cast or extruded light weight alloys.

- Financing

  Vinnova FFI – Sustainable Production

  Budget 7.76 MSEK (4.26 in-kind + 3.5 from Vinnova)

- Project duration

  Start 2020-10-15

  Finish 2023-06-30

- Partners

  Volvo Cars

  Scania

  Gestamp

  ArcelorMittal

  Hydro Extruded Solutions

  AGES

  EJOT

  RB&W

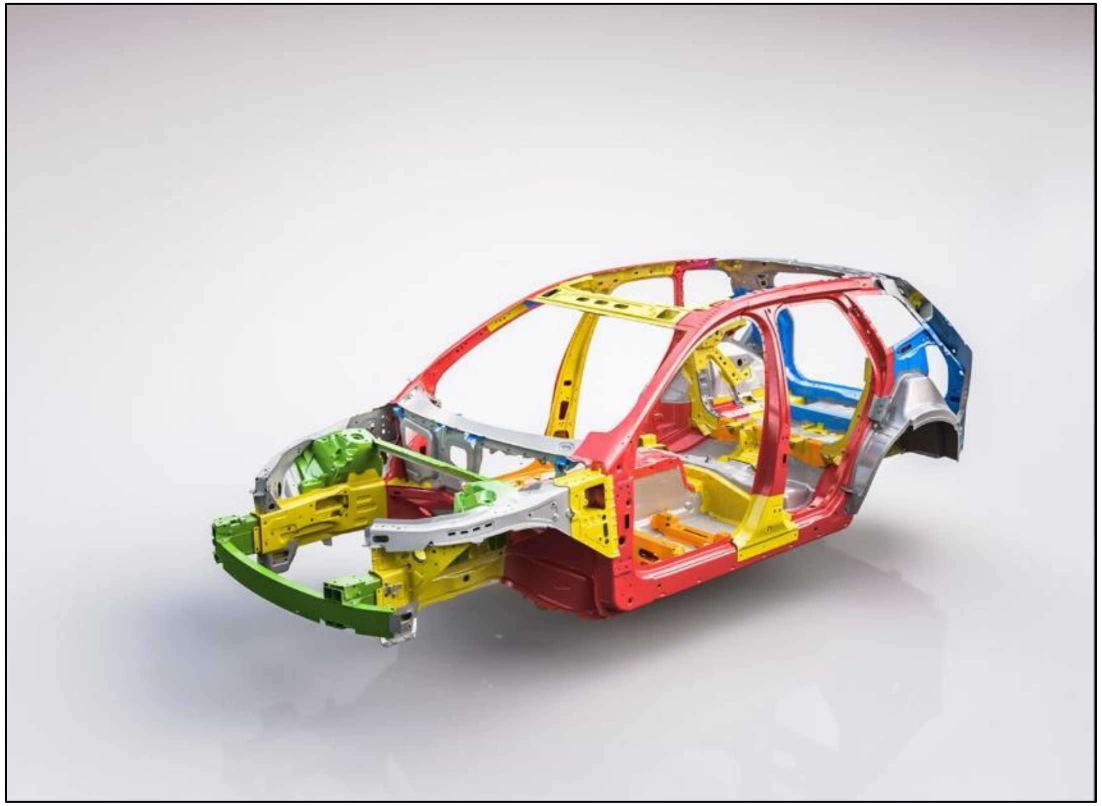
  Swerim

Current Challanges Background

- Aim: solve joining issues for multi-material combinations that cannot be joined by more traditional processes for multi-materials

- Focus: joining methods for difficult to join material combinations (e.g. cast or extruded aluminium to press-hardened boron steel)

- Driving range (electrical vehicles) with maintained collision safety

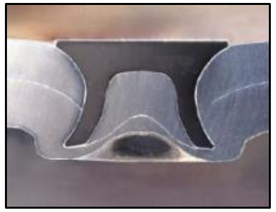


Volvo Cars

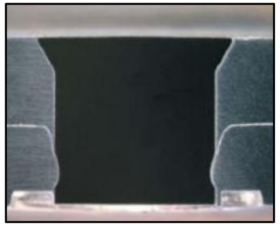
Current Challanges

- Limitations in traditional processes for multi-material combinations
- Generally constrained by the strength/thickness of the steel (~800 MPa, 1.5 mm)

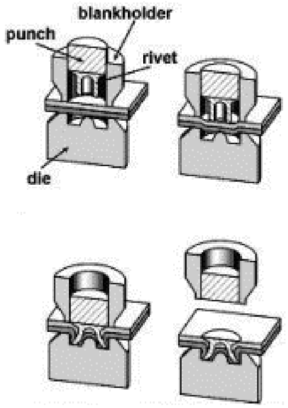
Self Peircing Riveting (SPR)



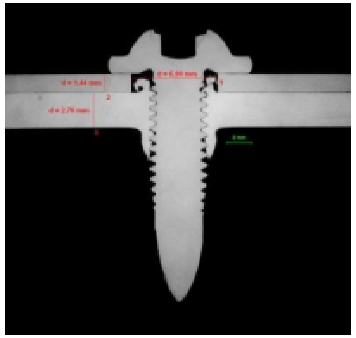
Hollow



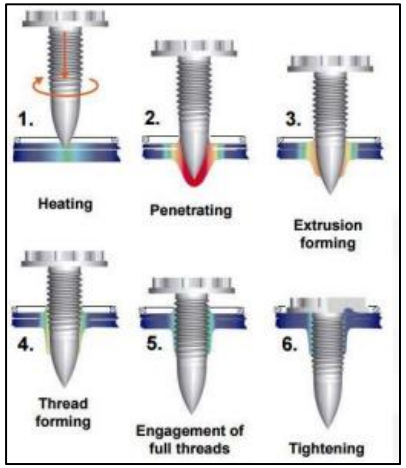
Solid



Flow Drill Screws (FDS)



Clearance hole



Sources: S. A. Westgate, R. Doo, F. Liebrecht, S. Braeunling, and T. Mattsson, "The development of lightweight self-piercing riveting equipment (March 2001)," 2001. [Online]. Available: http://www.twi-global.com/technical-knowledge/published-papers/thedevelopment-
of-lightweight-self-piercing-riveting-equipment-march-2001/.
"RIVTEC - Self Piercing Rivets." [Online]. Available: http://www.rivtec.com.au/157-self-piercing-rivets.
Sources: S. Engineer and G. Nygren, "EJOT FDS ® –EJOWELD ® –Flytborrande skruvsystem Friktionssvetssystem för höghållfasta material," 2010.
"EJOT FDS® -Flow drilling screw | Ejot& Avdel." [Online]. Available: http://www.ejot-avdel.se/sv/product/show/262

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Approach

- **Stage 1:** Ideal laboratory trials with focus on influence of material properties and process parameters.

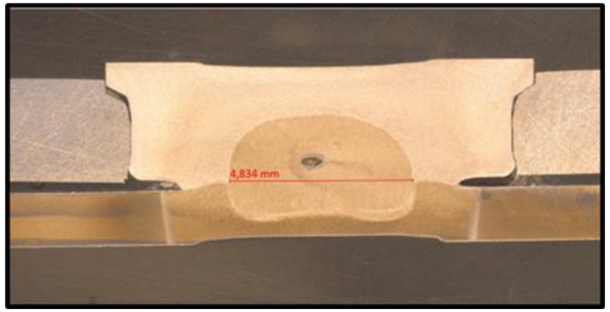
- **Stage 2:** Robustness of processes. Simulated production reality.

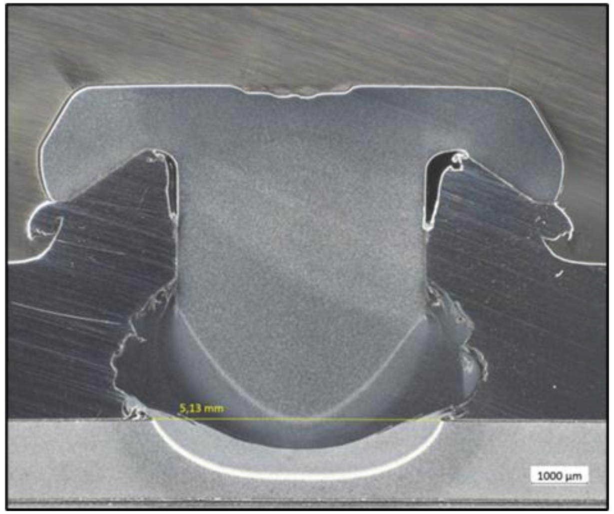
- **Stage 3:** Joining of components/ component like geometries.

- **Stage 4:** Joining of demonstrator.

Main focus joining methods:

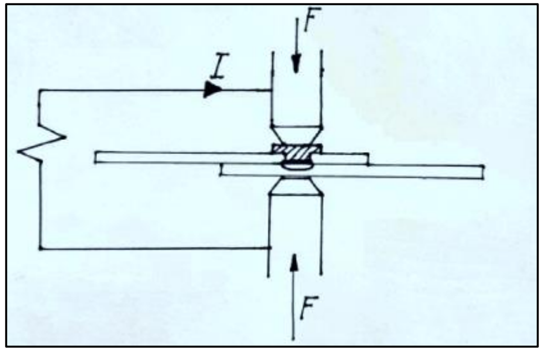
- Resistance Element Welding (REW)
- Friction Element Welding (FEW)



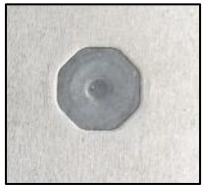


Resistance Element Welding

- **SpacPluc (RB&W) resistance element**
- Variant of RSW developed for the joining of dissimilar material combinations by using a resistance element and traditional RSW equipment.
- Requires that an element is punched in the cover sheet.
- Element is mechanically (pierce and clinch) locked to the panel attachment.
- The RSW electrodes are positioned over the element centre
- When pressure and electric current is applied a weld nugget is formed between the base sheet and the element



SpacPlug, Zn-Ni plated



SpacPlug – 1 mm Al, top

SpacPlug – 1 mm Al, bottom

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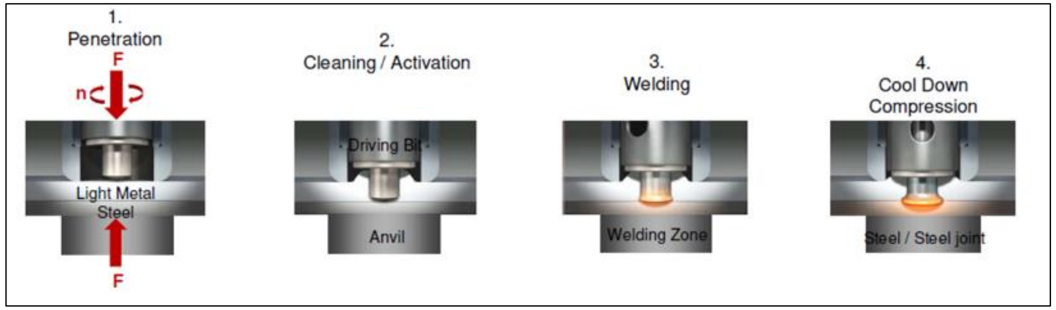
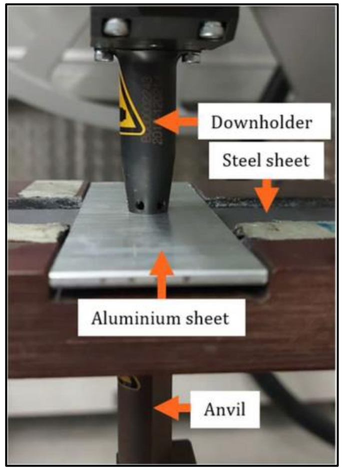
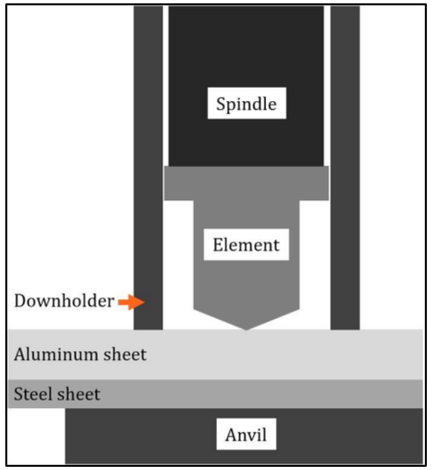
Friction Element Welding

- **EJOWELD (EJOT) = Thermomechanical process to join light material to steel**

1. Penetration: Force and rotation drives element through light material, which is softened and flows outward.
2. Cleaning: Tip reaches the surface of bottom sheet and friction increases. The rise in temperature plasticly deforms the bottom of the element and it starts to float outwards bringing the surface of the steel sheet with it.
3. Welding: Increase in force and rotation creates a friction weld between element and steel. Step stops when element has been deformed so that the head is resting on top of the aluminium top sheet surface.
4. Compression step: Rotation is stopped and a high pressure is applied to close any cracks that may have developed, and to properly set the element head into the aluminium bead.







SRE and CFF element from EJOT

Advantages and disadvantages

FEW:

+ Can be used on brittle UHS steel
+ Does not require pre-punched holes
+ No surface preparation needed
+ Small heat affected zone

- Requires two-sided access
- Specialized equipment needed

REW:

+ Can be used on brittle UHS steels
+ RSW equipment, knowledge and experience can be used
+ Fast method when cover sheet is prepared

- Requires two-sided access
- Requires a punching operation
- Potential stress concentration from hole generation

Stage 1: Ideal laboratory trials with focus on influence of material properties and process parameters.

Master Thesis:

<u>REW</u>: **Malte Eriksson**, KTH,

"Resistance Element Welding of Ultra High Strength Steel to Aluminium"

<u>FEW</u>: **Hilda Vestberg**, LTU,

"Friction Element Welding of Ultra High Strength Steels to Aluminium Alloys"

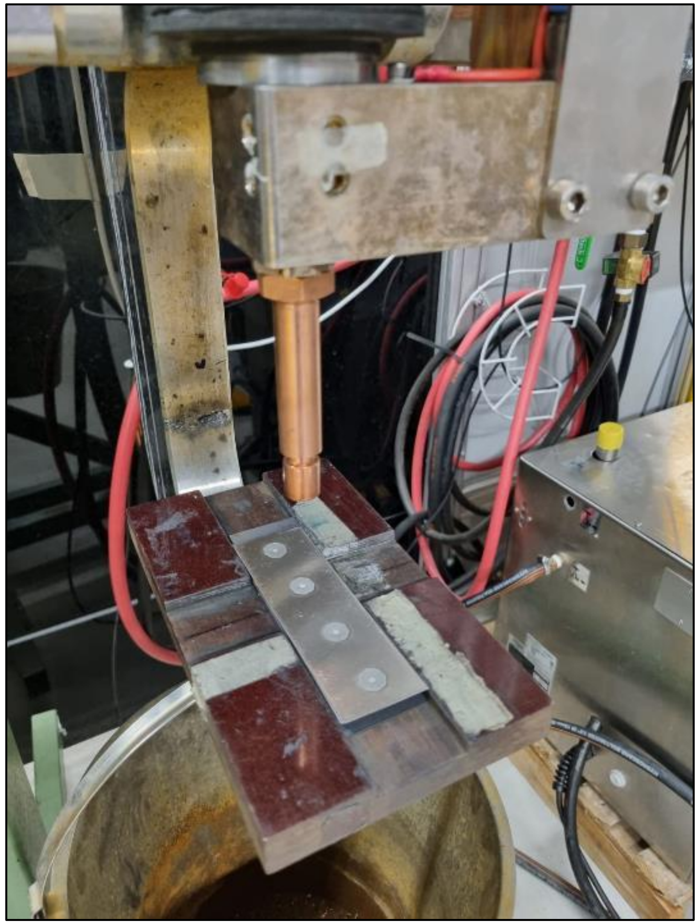
Base material *Coating* Thickness (mm)	**Usibor 1500** *AS150* 1.5	**Usibor 2000** *AS150* 1.5	**Ductibor 1000** *AS150* 1.5	**DP 1000** *GI50/50* 1.5	**Usibor 1500** *AS150* 1.0	**Usibor 1500** *AS150* 2.5	**Usibor 1500** *AS800* 1.5
Cast Al: 46 000 3.0 mm							
Cast Al: 43 500 3.0 mm							
Extruded Al: 6063 3.0 mm							
Cast Al: 46 000 4.7 mm							
Extruded Al: 6063 4.7 mm							
Sheet Al: 5754 3.0 mm							
Sheet Al: 5754 1.0 mm							

Joined combination	
Also joined with adhesive	

Stage 1: Methodology

REW

1. Optimization of process parameters
2. Generation of 1D-lobes
3. Cross-section analysis
4. Shear tensile and cross tension testing



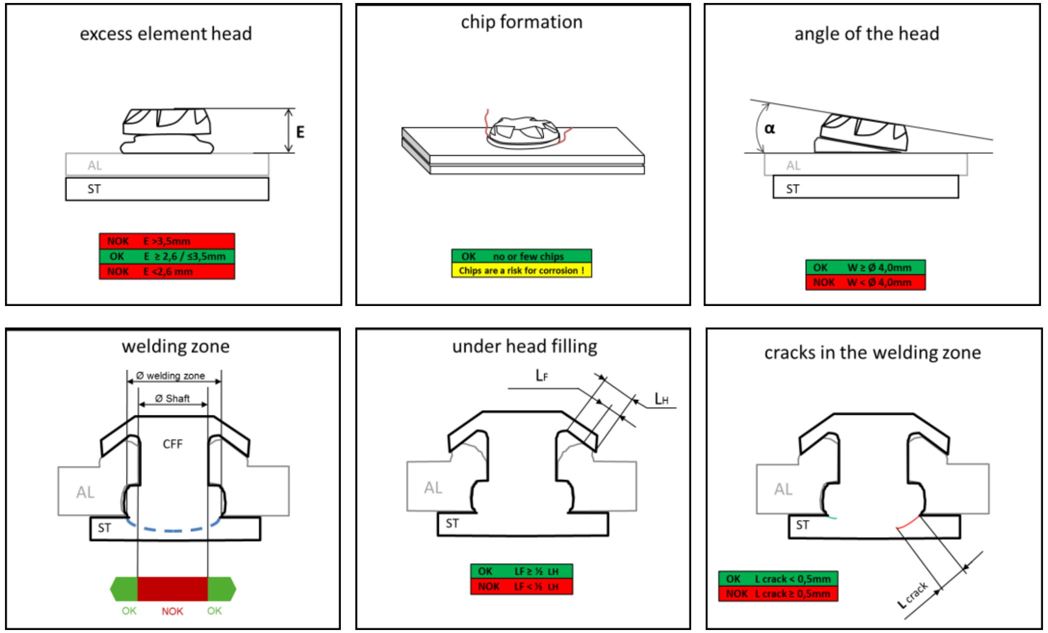
Stage 1: Methodology

FEW

1. Iterative process developed by EJOT for finding suitable parameters for penetrating aluminium

2. Optimisation of joining process by internal and external quality criteria

3. Shear tensile and cross tension testing



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Stage 1: Reference material combination

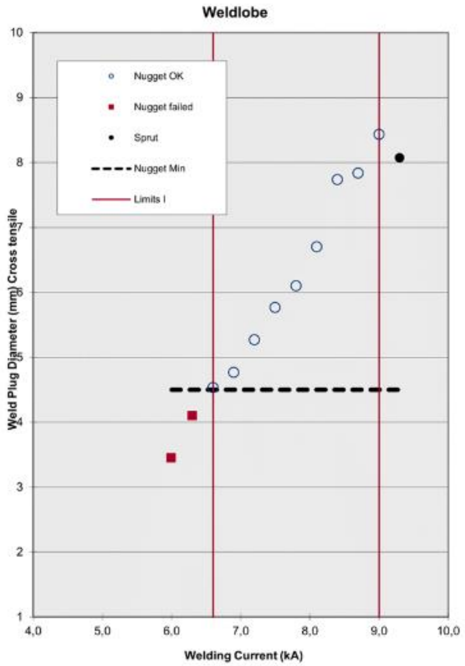
3.0 mm aluminium – 1.5 mm Usibor 1500

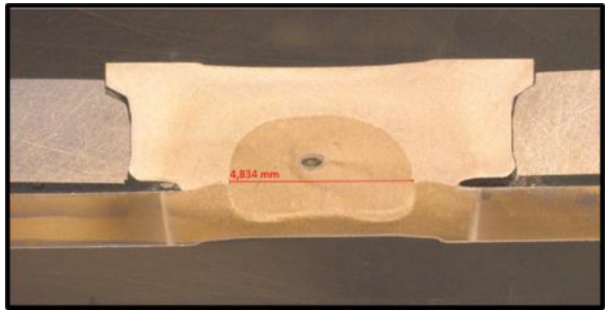
REW

- ΔI = 2.4 (6.6-9.0 kA)
- Shear 12.8 kN, Cross 4.3 kN

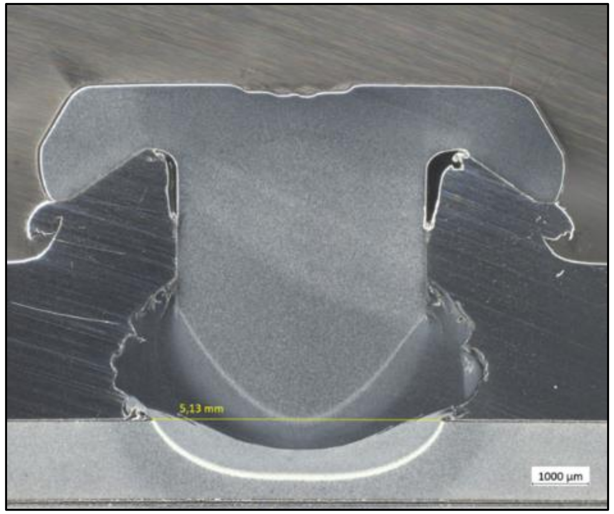
FEW

- Shear 11.8 kN, Cross 7.2 kN





REW – Same approved current range for extruded and cast aluminum
FEW – No difference in friction weld between combinations including extruded or cast aluminum. Very brittle top material tends to be prone to more chip formation around element head.



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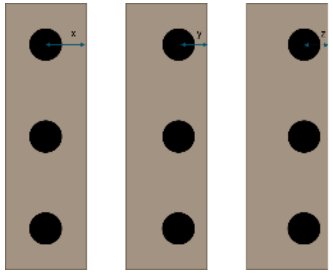
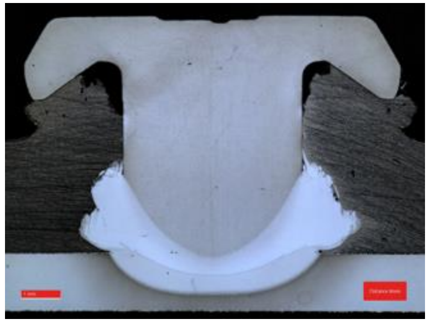
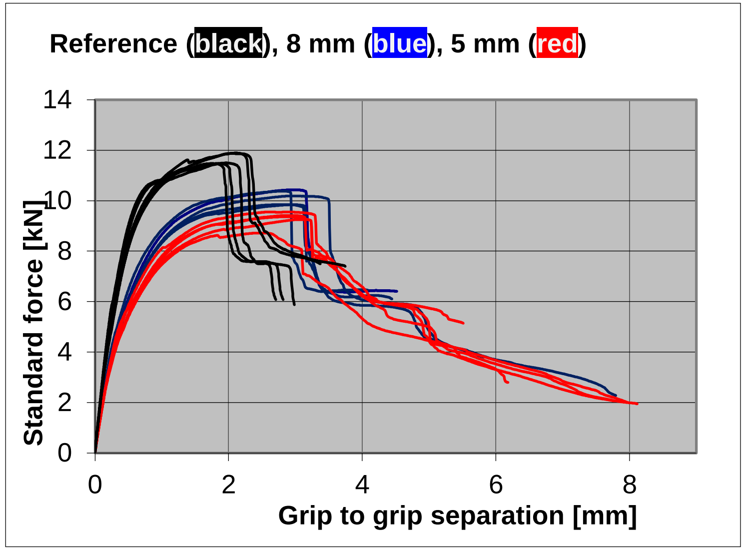
Stage 2: Robustness of processes. Simulated production reality.

Distance to edge





FEW

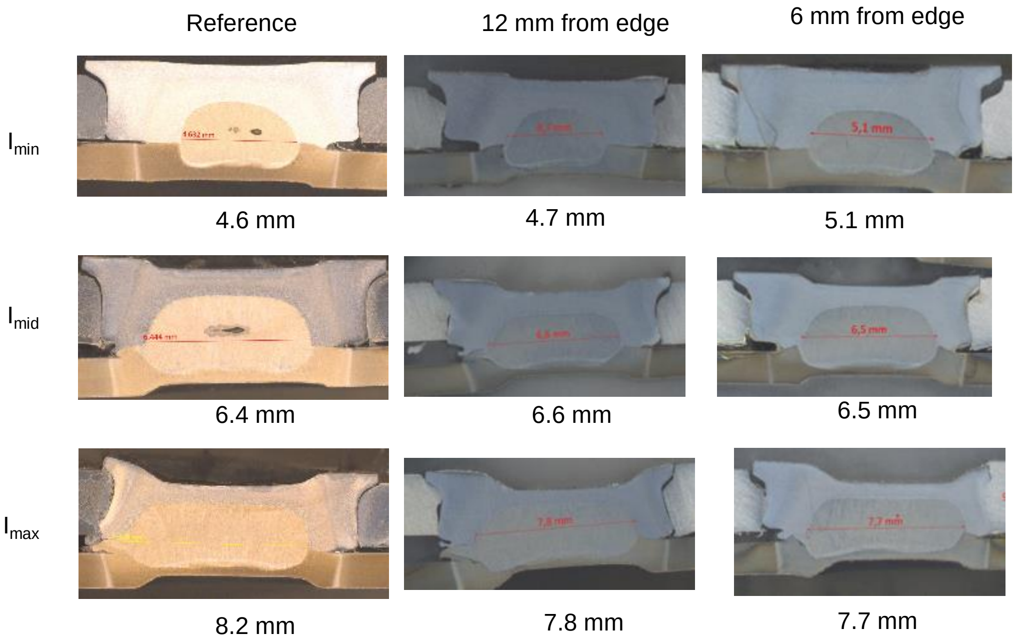


	Average force	Average Displacement
ID	kN	mm
Ref	11.62	3.12
8 mm	10.14	5.33
5 mm	9.26	7.11

The inner diameter of pressure module determines how close to flange you can be. Common to use SRE, in for example in door frames.

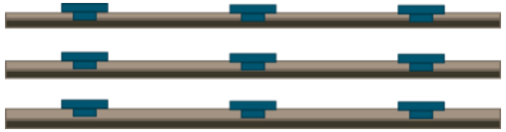
- CFF min flange width 17 mm
- SRE min flange width 14 mm

REW

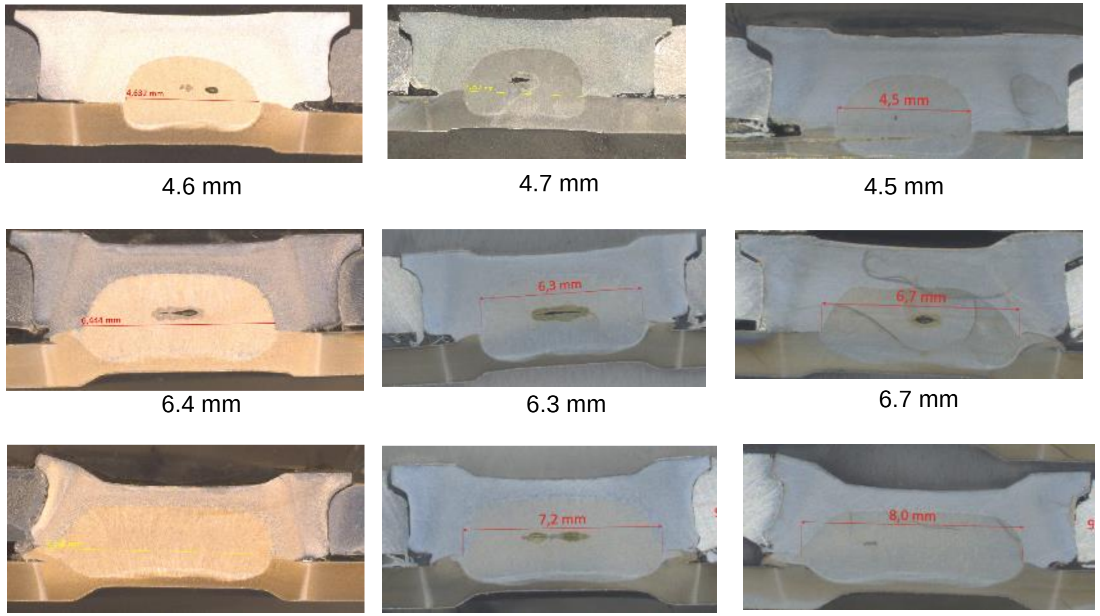


Stage 2: Robustness of processes. Simulated production reality.

Varying Al thicknes



REW

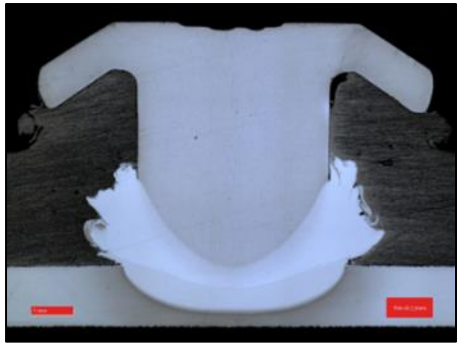


	Reference Al 3.0 mm	Al 3.4 mm	2.6 mm
I_{min}	4.6 mm	4.7 mm	4.5 mm
I_{mid}	6.4 mm	6.3 mm	6.7 mm
I_{max}	8.2 mm	7.2 mm	8.0 mm

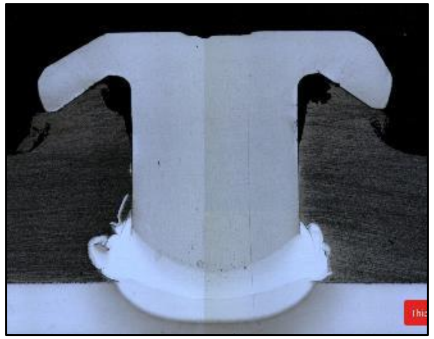
Constant current was used in the trials. Optimization of weld program or welding with adaptivity could increase the tolerance range.

FEW

Al 2.6 mm



Al 3.4 mm

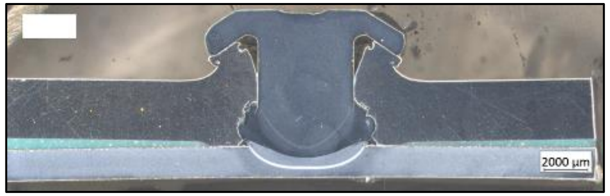


The tolerances can be expanded to allow thickness variations in aluminium (e.g. die cast)
Parameters in step 1 based on lower limit, assures correct under head filling.
Element length based on upper limit, assures tip reaches the steel before step 3 is initiated.

Stage 2: Robustness of processes. Simulated production reality.

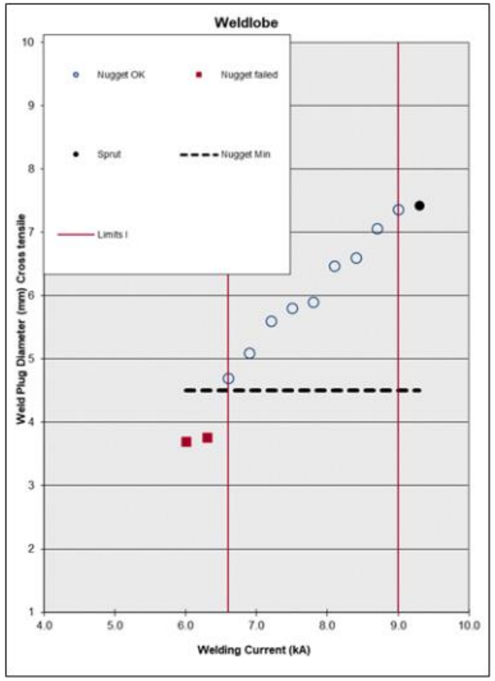
Adhesive

FEW

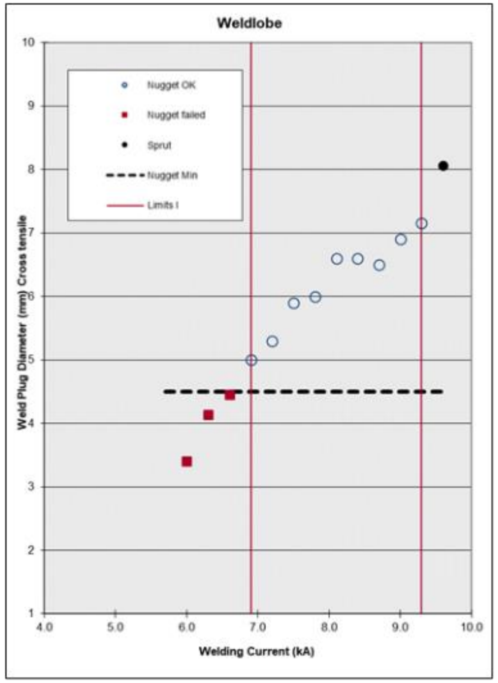


Pushed from joining area (approx. 2 mm)
Type and thickness (+50 %) does not influence cross section quality

REW



Reference without adhesive, ΔI=2.4 kA

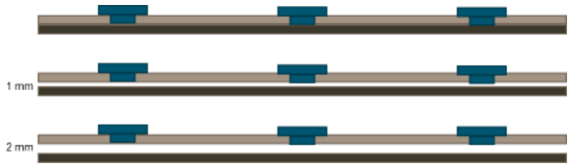


One component epoxy (0.8 mm), ΔI=2.4 kA

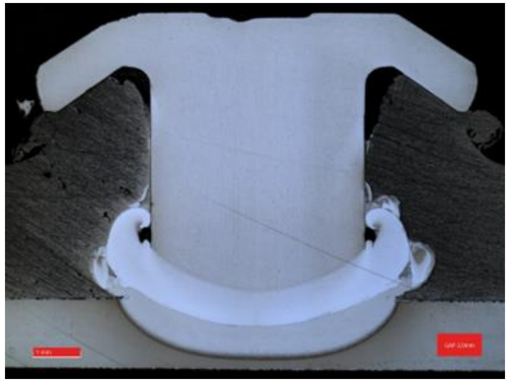
- Differences between welding sites was as big as differences between adhesive type and adhesive thickness
- Possible that the projection in the element decreases issues related to weldbonding
- All tested cases resulted in approved current ranges

Stage 2: Robustness of processes. Simulated production reality.

Gap between sheets



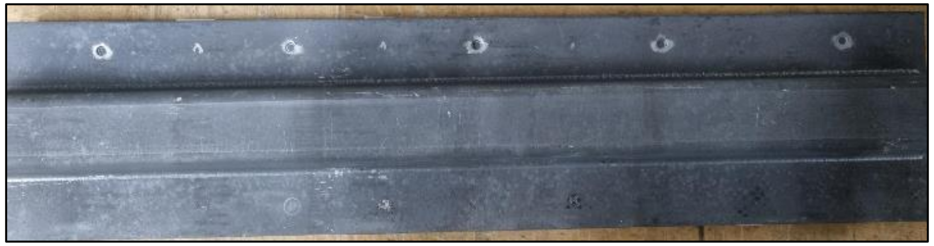
Still have not tested gap for REW



FEW

Reference

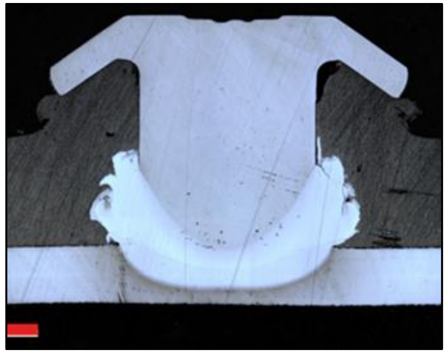
2 mm, 40 mm to gap



2 mm gap peeled

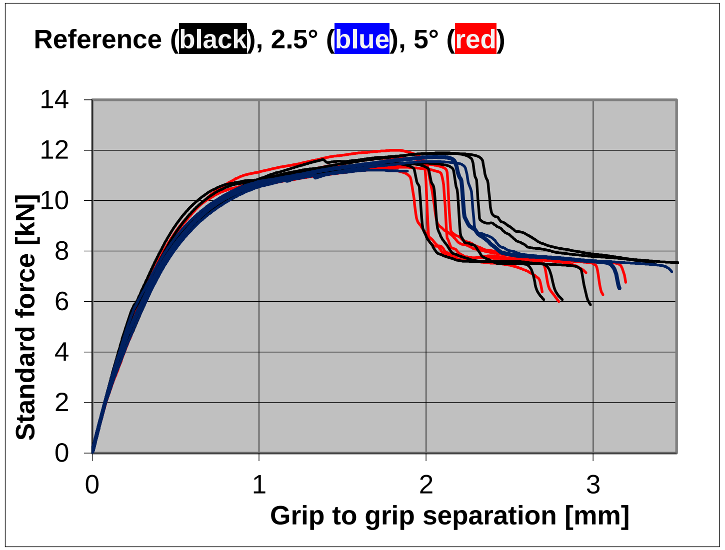
Stage 2: Robustness of processes. Simulated production reality.

Angle fault



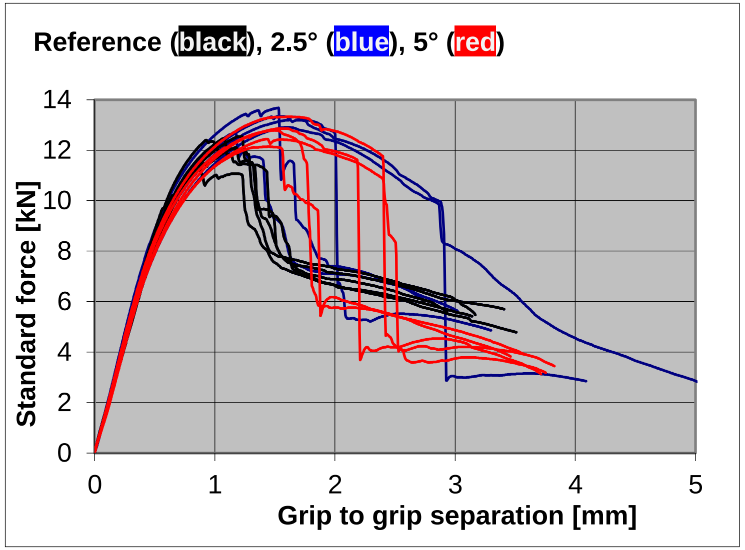
5°

FEW



	Average force	Average Displacement
ID	kN	mm
Ref	11.62	3.12
2.5°	11.52	3.01
5°	11.54	2.94

REW



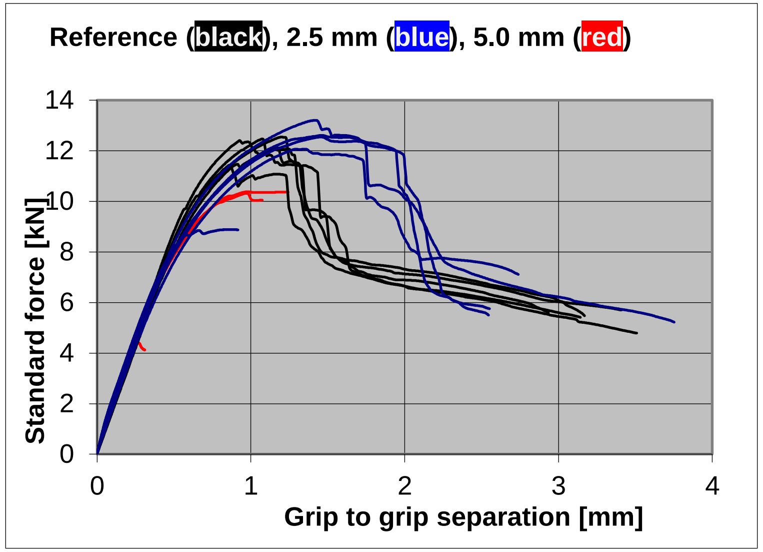
	Average force	Average Displacement
ID	kN	mm
Ref	13.44	3.60
2.5°	13.17	3.02
5°	12.71	3.75

5°

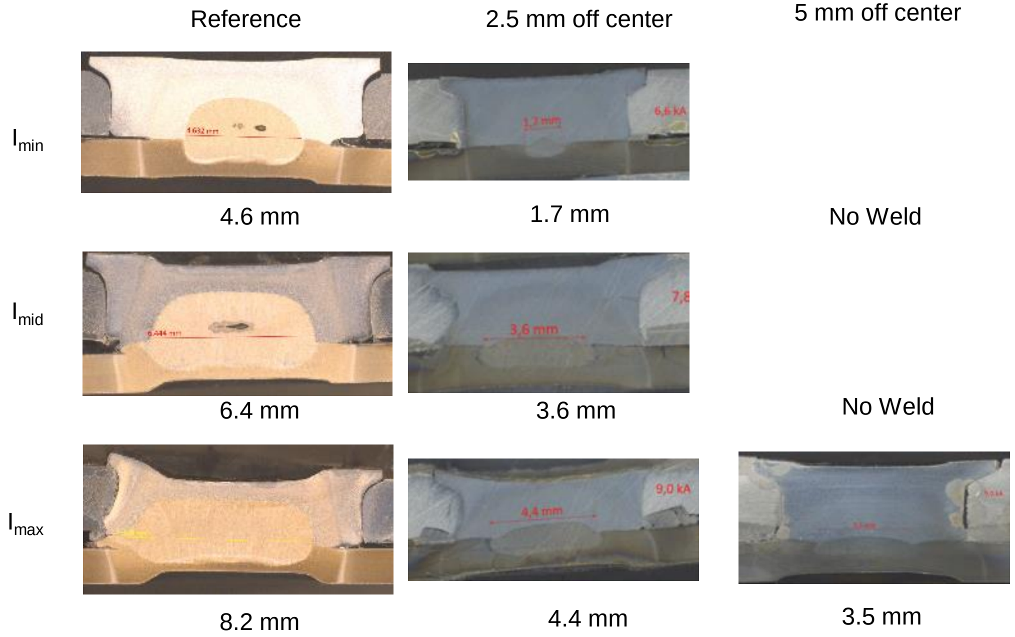
Stage 2: Robustness of processes. Simulated production reality.

Misalignment

REW



	Average force	Average Displacement
ID	kN	mm
Ref	13.44	3.60
2.5 mm	11.86	2.50
5 mm	5.43	0.54



Stage 2: Robustness of processes. Simulated production reality.

REW

- **Process time**
  - 0.5-1 s
- **Varying distance to edge**
  - The weld quality from tests with I_{min} and I_{mid} were not affected by the decreased distance to the edge, while the tests with I_{max} resulted in slightly decreased weld sizes
  - Possibly more prone to expulsion
  - Bulging of edge was seen when the element was placed 6 mm from edge
- **Angle fault**
  - No significant impact on weld nugget size was observed for the angle faults
  - Angle fault, up to tested 5°, does not affect tensile strength
- **Varying steel hardening parameters**
  - I_{min}, I_{max} and ΔI are very similar to reference case
- **Adhesive type and thickness**
  - Differences between welding sites was as big as differences between adhesive type and adhesive thickness
  - Possible that the projection in the element decreases issues related to weldbonding
- **Varying Al thickness**
  - \- 0.4 mm does not affect the weld nugget size at any current level.
  - \+ 0.4 mm somewhat affects the weld nugget size at I_{max}.
- **Misalignment of electrodes**
  - Decreased weld nugget size
  - 2.5 mm off-center does not significantly affect shear tensile strength and 5.0 mm off-center decreases shear tensile strength

- **Overall, the main disturbance factor that affects the quality is whether the resistance element is welded in its center**
- **Constant current was used in the trials. Optimization of weld program or welding with adaptivity could increase the tolerance range.**

Stage 2: Robustness of processes. Simulated production reality.

<u>FEW</u>

- **Process time**
  - 1-1,5 s: Average 1,3 s (of 169 trials)
- **Varying distance to edge**
  - Deformation of material increase closer to edge.
  - Inner diameter of pressure module determines. Common to use SRE in for example door frames. CFF min flange width 17 mm, SRE min flange width 14 mm.
- **Angle fault**
  - At more extreme angle fault (5°) the tilt causes under head filling to increase on one side.
  - Angle fault, up to tested 5°, does not affect tensile strength
- **Adhesive type and thickness**
  - Pushed from joining area (approx. 2 mm)
  - Type and thickness (+50 %) does not influence quality
- **Varying steel hardening parameters**
  - OK welds using internal and external criteria, no difference in shear tensile strength
- **Varying Al thickness**
  - ± 0,4 mm affects penetration into steel and under head filling
  - The tolerances can be expanded to allow thickness variations in aluminium (e.g. die cast)
  - Parameters in step 1 based on lower limit, assures correct under head filling.
  - Element length based on upper limit, assures tip reaches the steel before step 3 is initiated.
- **Gap between sheets**
  - Up to 2 mm gap result in OK welds using internal and external criteria
  - Plug failure in peel test on hat profiles
- **Overall, the joint quality is not significantly affected by the disturbance factors.**

Remaining Challenges

- Stage 2 – Robustness
  - Joining trials using cast ”snake-tool”

- Stage 3 – Component
  - Disturbance factors which the largest impact are scaled up to hat-profiles and joined at company sites

- Stage 4 – Demonstrator

Conclusions and further work

- High quality joints are obtained for both investigated REW and FEW methods. Process optimization enables a robust joining process of different materials and light-weight combinations, also taking into account possible disturbance factors.

Future work:

- How to incorporate the joining processes into a production line
- In-line quality assurance
- Possibilities with adaptive welding systems for REW