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AffordabLe LIghtweight Automobiles AlliaNCE

Future of Automotive Lightweighting Day

September 19, 2019

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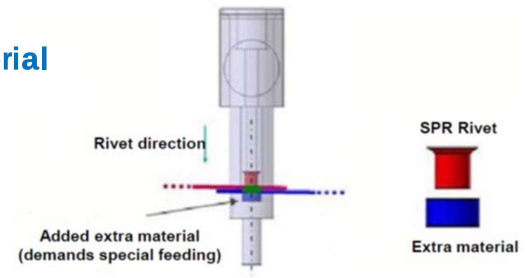
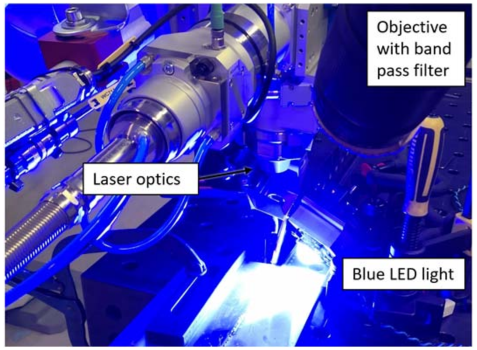
Process technologies – Joining

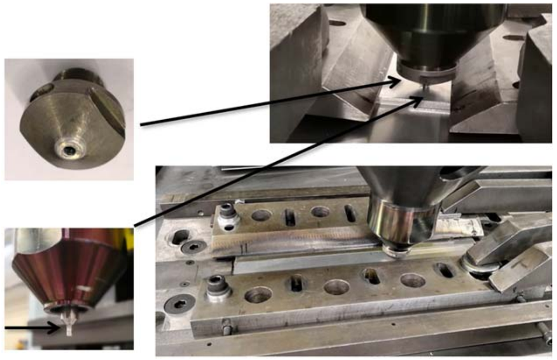
Joakim Hedegård / Swerim

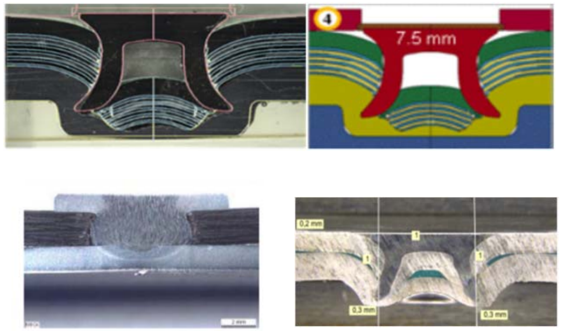
Process development – Joining overview

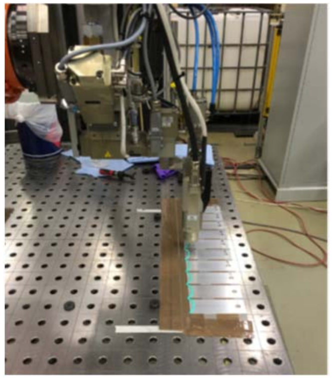
- Innovative-joining test matrix with 27 material combinations of interest from partners, and possible joining methods identified
- Evaluations of joints mainly made by the partners with “ownership” (comparisons with earlier results essential)
- The winning process solutions were further developed for use on demonstrators
- The joining processes studied were:
  - Laser welding: autogenous / with oscillation optics / with filler material
  - Advanced MIG welding
  - Friction Stir Welding (FSW) + FSW Stationary Shoulder (FSWSS)
  - Self Pierce Riveting (SPR) + Advanced SPR (PER)
  - Flow Drill Fasteners (FDF)
  - Resistance Spot Welding (RSW)
  - Adhesive bonding
  - Hybrid joining: Adhesives + SPR
  - Resistance Element Welding (REW)
  - Friction Element Welding (FEW)





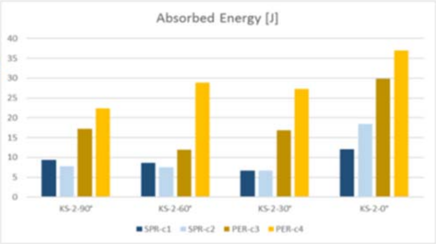


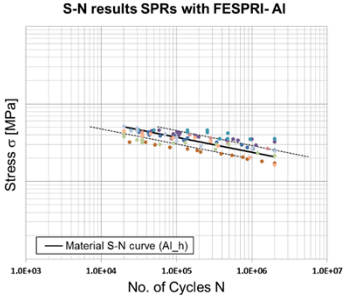


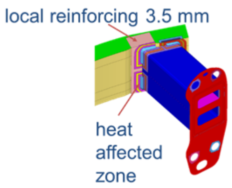


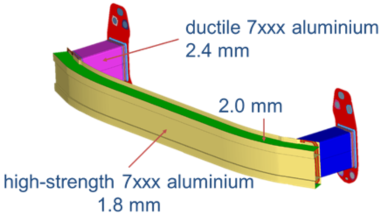
Validation - overview

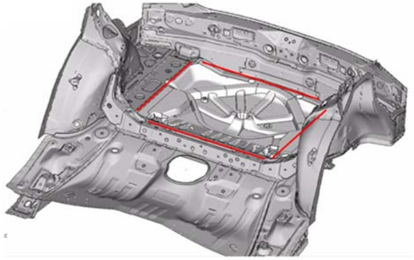
- **Evaluation and validation of joints were mainly made by partners with “ownership” (comparisons with earlier results essential)**
- **Initial visual inspection and: (depending on the demands for the applications)**
  - **tensile testing**
  - **high-speed imaging**
  - **fatigue tests**
  - **simulations**
  - **elevated and reduced temperature**
  - **humidity**
  - **creep testing**

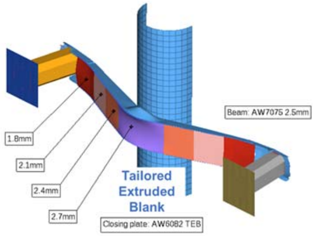


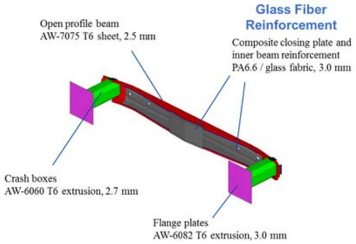












Welding of high-strength aluminium for bumper systems

Goals:

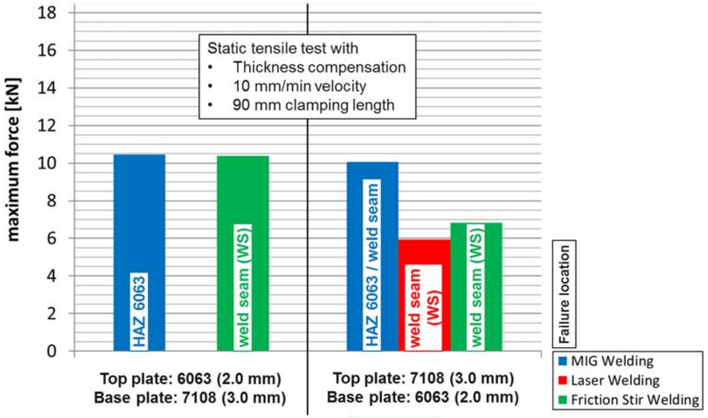
- Performance of different welding methods (MIG, FSW, Laser) after joining of hybrid high-strength 6xxx-7xxx-aluminium
- Determination of the best joining solution for bumper systems

Investigations of

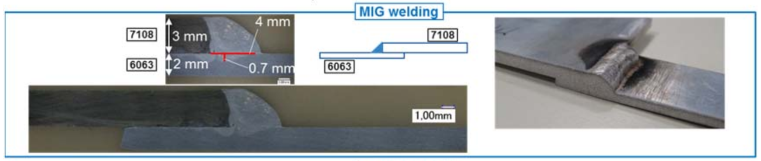
- microhardness, strength and macroscopic behaviour of different welding methods (MIG, FSW, Laser) and different welding conditions (material combination, thickness, welding position)

Result:

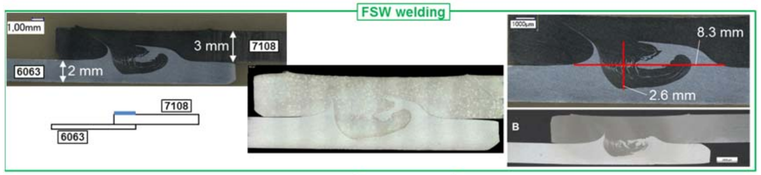
- Laser welding tends to give some imperfections combined with small weld seam width and high investment cost
- Friction stir welding tends to give lower tensile strength combined with high efforts (clamping) for welding and high investment cost
- MIG welding is the favoured method due to high strength, low investment cost, disadvantage: higher heat input



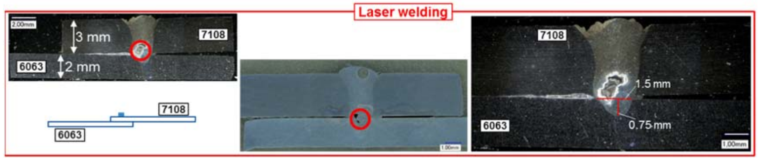
MIG welding



FSW welding



Laser welding



Mechanical joining of high-strength aluminium, Feasibility study

Goals:

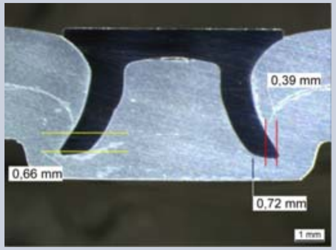
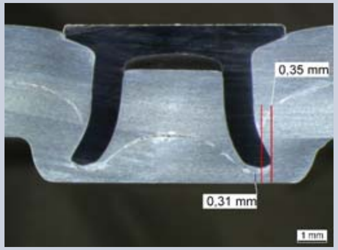
- Joining of high-strength 6xxx aluminium at RT (without temperature)
- Feasibility study

Investigations of

- different joining processes (self-pierce riveting and clinching)
- different material conditions (w-temper + different natural ageing, T6-temper)

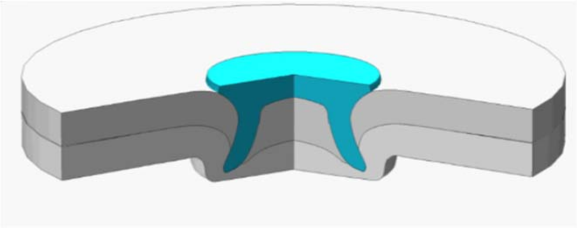
Result:

- With adjusted parameters mechanical joining is possible for high-strength 6xxx aluminium alloys
  - in a natural aged condition 0-7 days after solution annealing and quenching
  - in T6 condition

	AW-6xxx HS T4	AW-6xxx HS T6
Cross section		
Rivet:	C 5,3 x 6,0 H4	HD2 5,3 x 6,0 H4
Die:	F100 160	F100 160
Head:	0 mm	0 mm
Force:	59,36 kN	64,22 kN

Validation of SPR for aluminium sheet

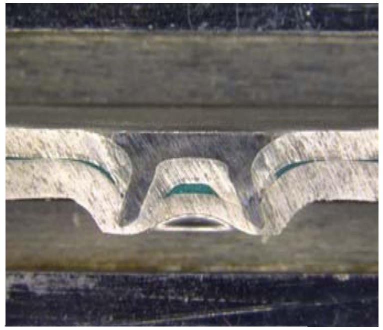
- SPR is a mechanical joining method in which a rivet is pressed through the top material into the bottom material where the bottom material and the rivet will deform to achieve interlocking.

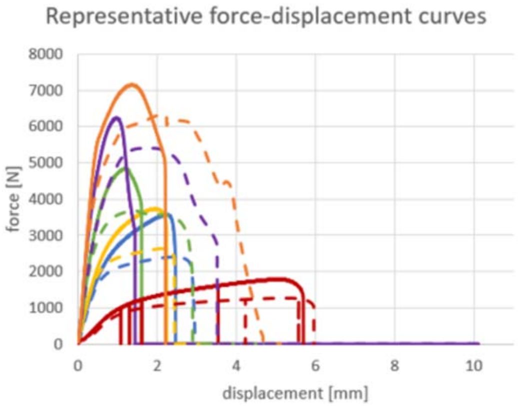


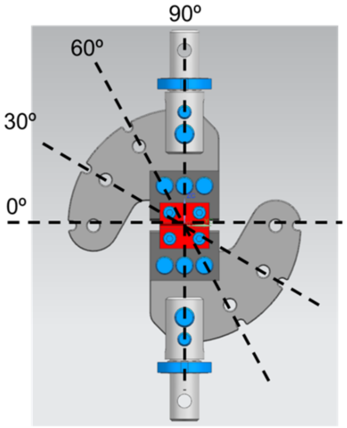
No Adhesive...

Porosity in adhesive application due to quilting down to adhesive not being optimised and clamping strategy incorrect...

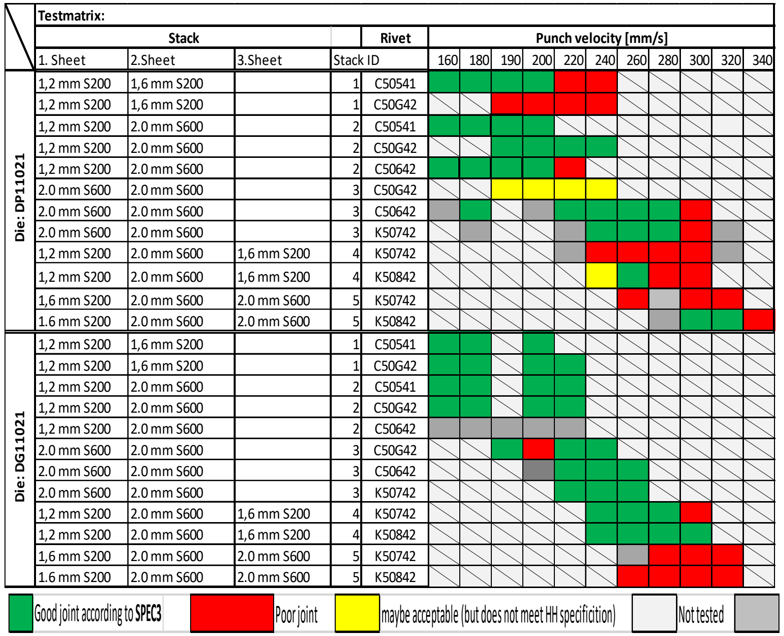
Optimised adhesive, riveting and clamping...







KS2-testing in different load directions
Data used for simulations



Testmatrix:

	Stack				Rivet	Punch velocity [mm/s]										
	1. Sheet	2.Sheet	3.Sheet	Stack ID		160	180	190	200	220	240	260	280	300	320	340
Die: DP11021	1,2 mm S200	1,6 mm S200		1	C50541	🟩	🟩	🟩	🟩	🟥	🟥	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	1,6 mm S200		1	C50G42	⬜	⬜	🟥	🟥	🟥	🟥	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	2.0 mm S600		2	C50541	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	2.0 mm S600		2	C50G42	⬜	⬜	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	2.0 mm S600		2	C50642	🟩	🟩	🟩	🟩	🟥	⬜	⬜	⬜	⬜	⬜	⬜
	2.0 mm S600	2.0 mm S600		3	C50G42	⬜	⬜	🟨	🟨	🟨	🟨	⬜	⬜	⬜	⬜	⬜
	2.0 mm S600	2.0 mm S600		3	C50642	▩	🟩	⬜	▩	🟩	🟩	🟩	🟩	🟥	⬜	⬜
	2.0 mm S600	2.0 mm S600		3	K50742	⬜	▩	⬜	⬜	▩	🟩	🟩	🟩	🟥	▩	⬜
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50742	⬜	⬜	⬜	⬜	▩	🟥	🟥	🟥	🟥	▩	⬜
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50842	⬜	⬜	⬜	⬜	⬜	🟨	🟩	🟥	🟥	⬜	⬜
	1,6 mm S200	2.0 mm S600	2.0 mm S600	5	K50742	⬜	⬜	⬜	⬜	⬜	⬜	🟥	▩	🟥	🟥	⬜
	1.6 mm S200	2.0 mm S600	2.0 mm S600	5	K50842	⬜	⬜	⬜	⬜	⬜	⬜	⬜	▩	🟩	🟩	🟥
Die: DG11021	1,2 mm S200	1,6 mm S200		1	C50541	🟩	🟩	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	1,6 mm S200		1	C50G42	🟩	🟩	⬜	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	2.0 mm S600		2	C50541	🟩	🟩	⬜	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	2.0 mm S600		2	C50G42	🟩	🟩	⬜	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜
	1,2 mm S200	2.0 mm S600		2	C50642	▩	▩	▩	▩	▩	⬜	⬜	⬜	⬜	⬜	⬜
	2.0 mm S600	2.0 mm S600		3	C50G42	⬜	⬜	🟩	🟥	🟩	🟩	⬜	⬜	⬜	⬜	⬜
	2.0 mm S600	2.0 mm S600		3	C50642	⬜	⬜	⬜	▩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
	2.0 mm S600	2.0 mm S600		3	K50742	⬜	⬜	⬜	⬜	🟩	🟩	🟩	⬜	⬜	⬜	⬜
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50742	⬜	⬜	⬜	⬜	⬜	🟩	🟩	🟩	🟥	⬜	⬜
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50842	⬜	⬜	⬜	⬜	⬜	🟩	🟩	🟩	🟩	⬜	⬜
	1,6 mm S200	2.0 mm S600	2.0 mm S600	5	K50742	⬜	⬜	⬜	⬜	⬜	⬜	▩	🟥	🟥	🟥	⬜
	1.6 mm S200	2.0 mm S600	2.0 mm S600	5	K50842	⬜	⬜	⬜	⬜	⬜	⬜	🟥	🟥	🟥	🟥	⬜

🟩 Good joint according to **SPEC3** 🟥 Poor joint 🟨 maybe acceptable (but does not meet HH specificition) ⬜ Not tested ▩

Optimisation of rivet, dye and punsch velocity (force) for different 2 and 3 layer AA 6016 stacks

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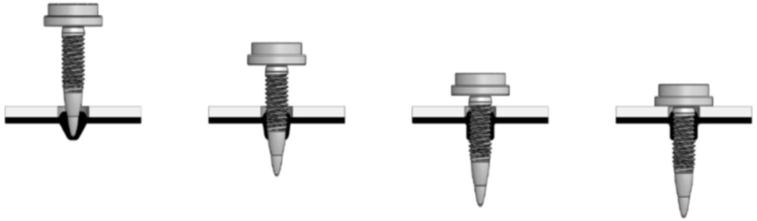
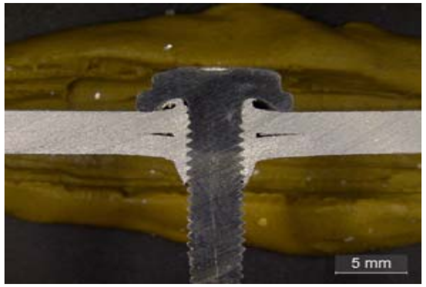
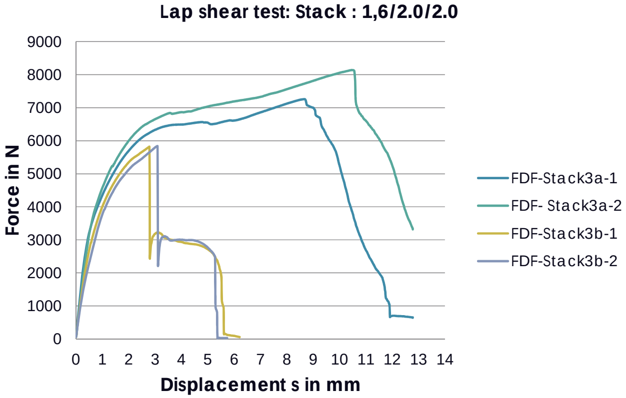
Validation of FDF/FDS – Flow drill fastening/screwing for aluminium sheet

Flow Drill Fastening (FDF) or Flow Drill Screwing (FDS) is a process where a fastener is rotated at high speed and pressure against the parts to be joined. Friction heat softens the material and the fastener creates a thread in the materials which are finally clamped by an applied torque.

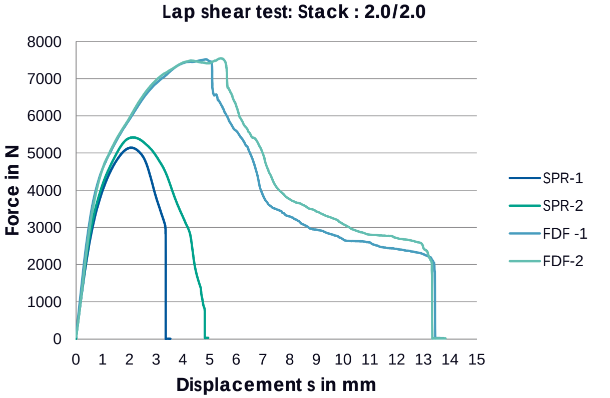




3-stack AA 6016 after lap-shear test



Force-displacement curve for load applied on different sheets, 1,6 resp 2,0 mm, in 3-stack AA 6016



Comparison of force-displacement curves for SPR and FDF on 2-stack AA 6016 2,0 mm

Report on Joining Processes Testing & Validation

AffordabLe Lightweight Automobiles AlliaNCE

European Commission

Horizon 2020
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AffordabLe LIghtweight Automobiles

ALLIANCE

Collaborative Project
Grant Agreement Number 723839
Start date of the project: October 1st, 2016, Duration: 36 months

Deliverable D 3.5

Validation of advanced joining solutions

Status: Final

Lead contractor for this deliverable: *Swerim AB*

Due date of deliverable: **31.03.2019**
Actual submission date: **27.05.2019**

Coordinator:

Dr.-Ing. Sama Mbang
Daimler AG
Mercedesstrasse 137 – 70327 Stuttgart - Germany
Phone +49 7031 90 76929, PC-Fax +(49) 711 3052 11 84 95
E-mail sama.mbang@daimler.com

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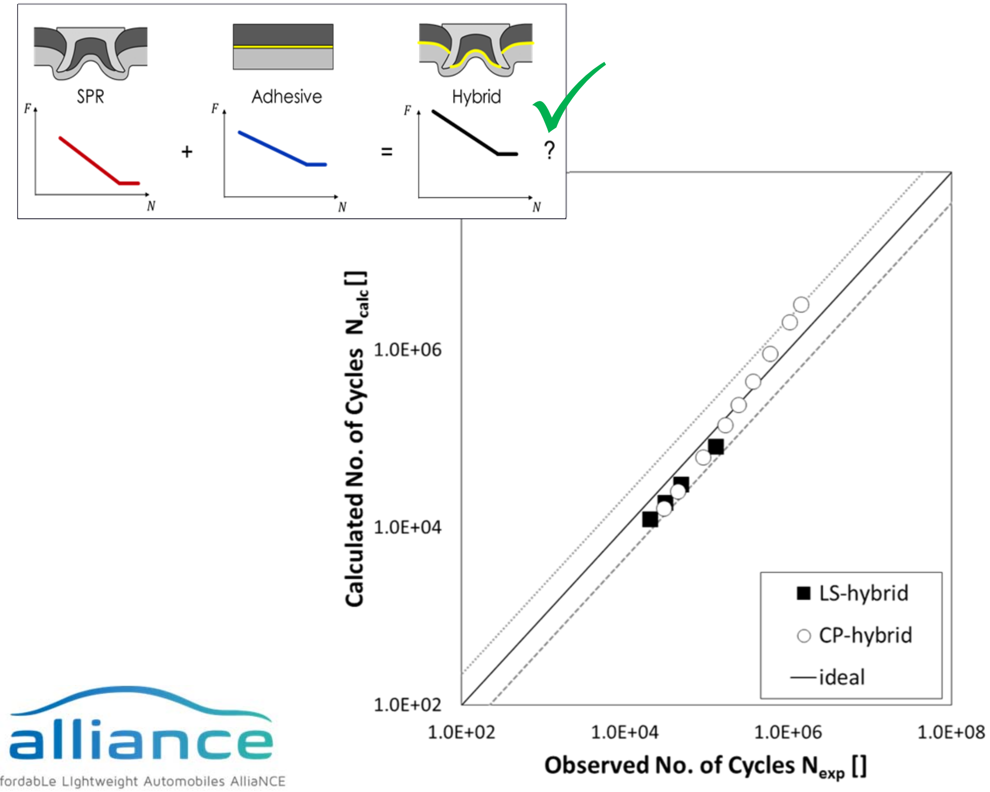
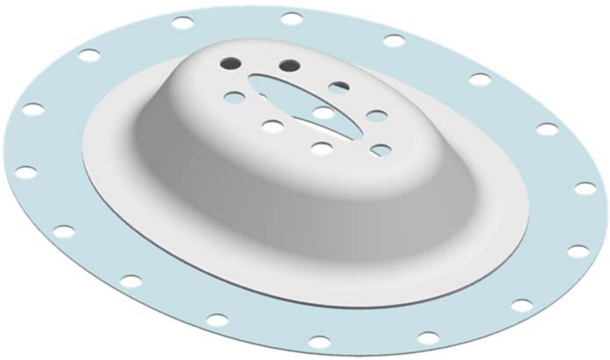
Validation of simulation methodology

- Material and thickness mix is oriented on (virtual) strut tower and wheelhouse from WP5
- Validation on coupon level (lap shear and coach peel):
  - Superposition of calculated fatigue life for SPR and adhesively bonded connections



- Further validation in WP6 on component level (bowl specimen)



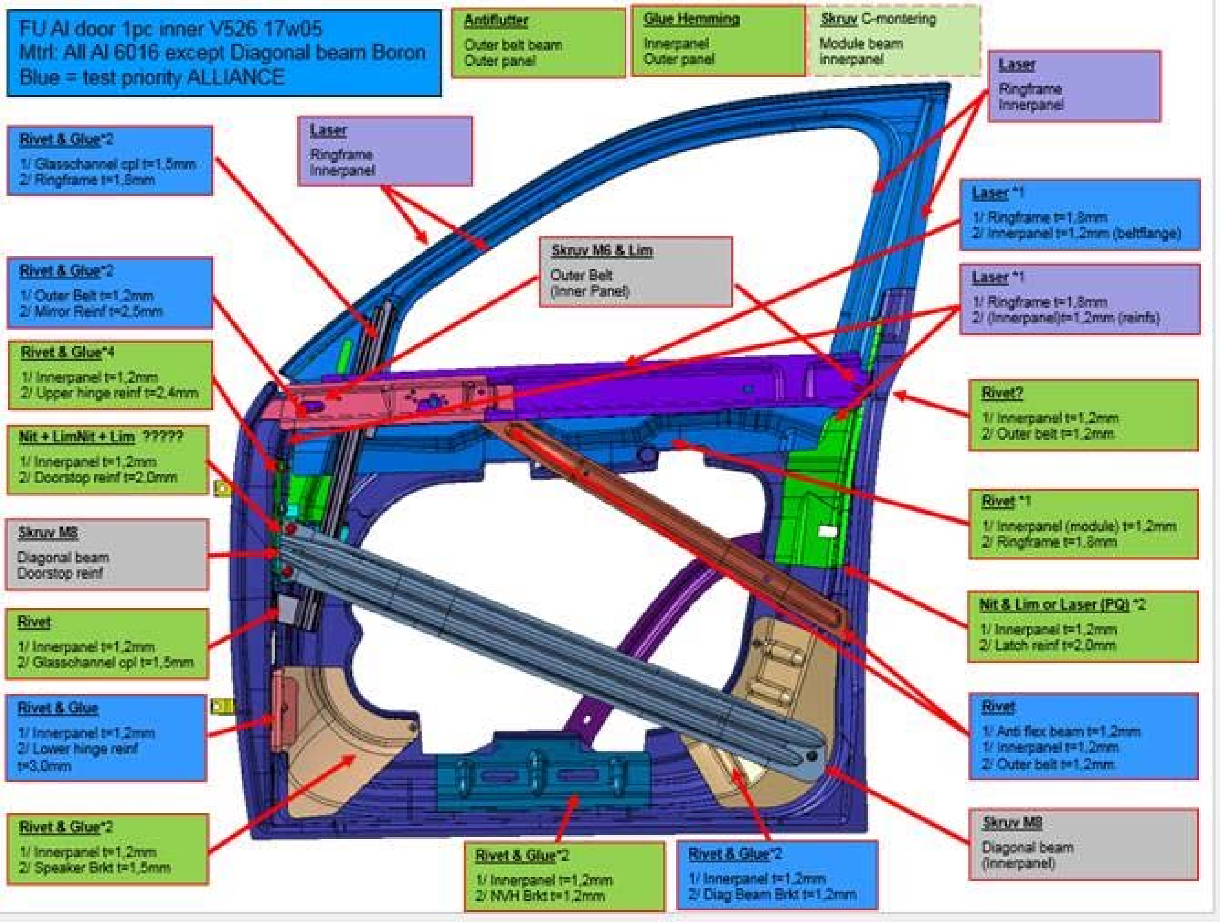
Door demonstrator – joining

Goals:

- Investigate performance of joining methods to find cost efficient solutions for Alu door
- Identifying best joining solutions

Joining investigations:

- Pure laser / oscillating optics / with wire
- SPR & Advanced SPR
- Hybrid: SPR + Adhesives
- FDF / FDS / FEW
- Material influence



Hood demonstrator – joining - tempered spotweld technology

Application:

- Reinforcement integration for lightweight design

Objective:

- Join AA5182 alloy plane patches on plane frame sheet before stamping operations

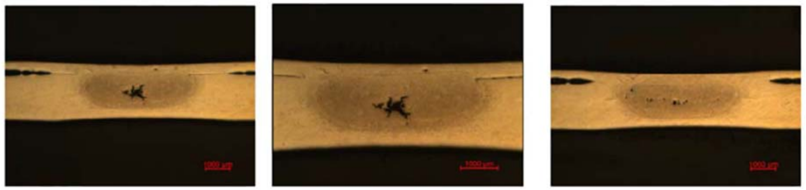
Thicknesses involved:

- 0.6 mm AA5182 sheet
- 2.0 mm AA5182 reinforcements sheet
- Thickness ratio 333 %


Reinforcement 2.0 mm - NOVELIS

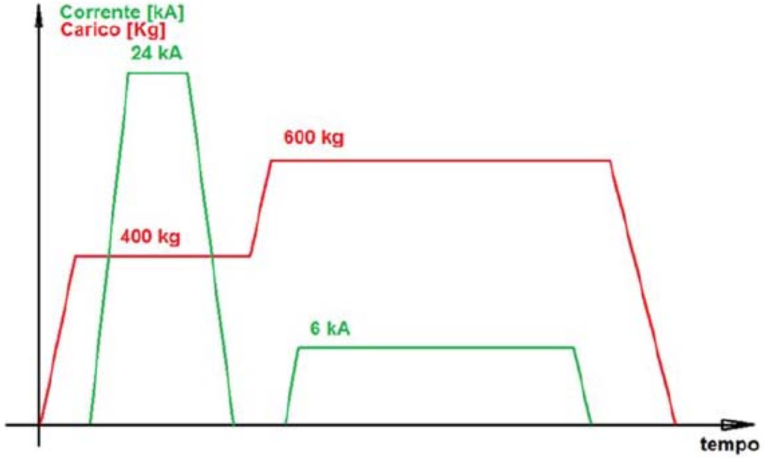
Base plate 0.6 mm - NOVELIS

Final experimental campaign results:


Test 1: 22 Ka

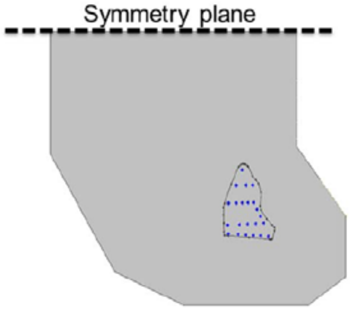
Test 1: 23 Ka

Test 1: 24 Ka

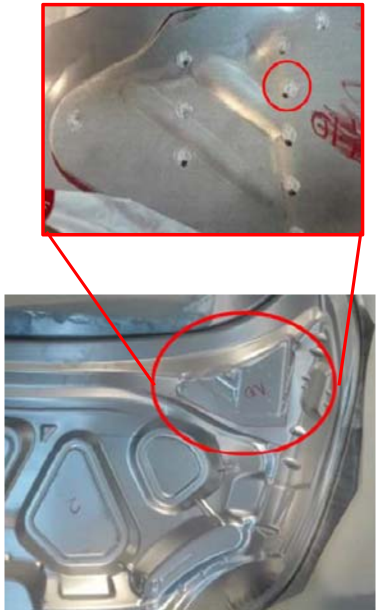


Process parameters for welding operation

Weld configuration	Material base	Material top	Thickness base [mm]	Thickness top [mm]	Current max [kA]	Electrode load [kg]	Temper Current max[kA]	Electrode load [kg]
Overlap fillet	AA5182	AA5182	0.6	2.0	24	400	6	600



Weld pattern on hood



Final characteristics of process

- Laser welding of aluminium: the possibility to avoid utilization of filler material was evaluated. An oscillating beam could not fully avoid cracking. But it is believed that results can be improved with more work. Joining speed ranges of 3.5 – 5 m/min. Of redundancy reasons, a lightweight door is prepared with laser welding using filler material.
- Advanced MIG-welding: modern control systems offer many options for adapted heating and melting. Material softening in the HAZ (heat-affected zone) could be reduced, although not fully avoided. For most cases, the results are fully acceptable. Joining speeds were around 0.6 m/min.
- FSW: no HAZ softening in aluminium joints (low heat input). Tool geometry and its capability to achieve suitable level of stirring (material-mixing) very important for joint strength. FSW does not add weight in terms of filler material, and the method is quite sustainable (electricity required, but no emissions and little wear). Joining speeds were around 0.2 m/min but higher speeds are possible with strong fixturing. The FSW Stationary shoulder method introduced even less heat but needed extra strong tool material and modified tool geometry to manage stirring the 7XXX aluminium alloy.
- SPR: suitable material stack combinations and die and rivet geometries were identified for many cases. For demanding material combinations utilizing an extra bracket can be an enabler. The bracket offers a softer material where the rivet can be set (deform and interlock) properly. This method variant is called PER (Plug-Element-Riveting). It adds weight with an extra bracket but can enable otherwise impossible material combinations to be joined with SPR. Typical joining speed is around one element per sec.
- FDF is an alternative to SPR and comparisons have been made between these methods for material combinations of interest. FDF received higher shear tensile joint strength and is removable and resettable. But the FDF element weight is higher than for SPR. Both successfully used in hybrid joining with adhesives.

Final characteristics of process

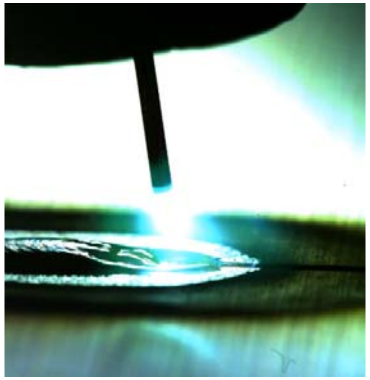
- RSW: challenges increase with reduced material thickness and large differences in material thicknesses. Also, when more aluminium materials are used in car bodies and parts new challenges arise. Good results were achieved for the evaluated thin material combinations and a lightweight hood can be realized. Typical joining speed was around spotweld one per second.

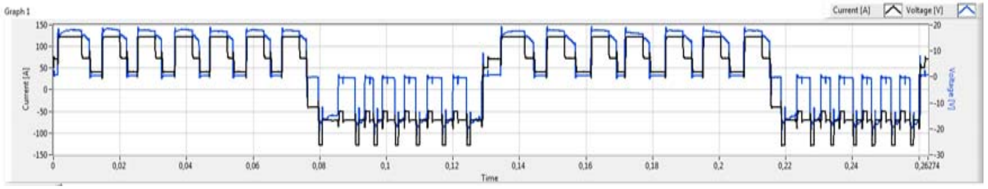
- Adhesives: studied for parts in aluminium and plastics and mixed materials. Successful results were achieved when correct pre-preparation was applied. Many joints were evaluated in different environments; hot and cold temperatures, humidity, oil, and the creep performance was also studied. Approved results, and a lightweight car floor can be realized. Adhesives (or advanced MIG-welding) will also be used for new and lighter crash management systems.

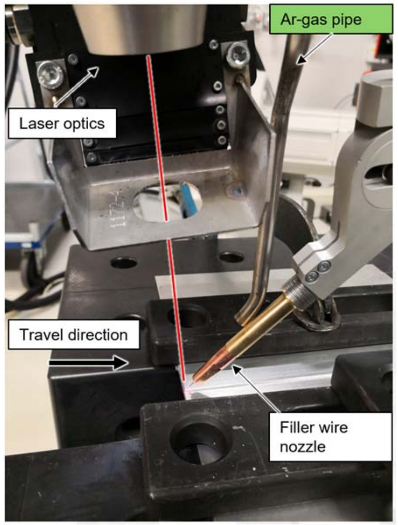
- Hybrid joining FEW & REW: these methods are combinations of welding and mechanical interlocking. FEW received better results in terms of high shear strength and enable successful joining of two very different material types. A new FEW version (SRE) is available with a lighter fastening element, although not the same joint strength is reachable. FEW will be utilized when other options are less suitable, and REW will find its applications, especially where an SPR method is already utilized on a component and extra parts mounting is needed in this area (and RSW is accessible). Both FEW and REW will often be used in combination with adhesives.

Conclusions

- It is evident that the preferred joining processes differs from case to case, it is connected not only to joint strength and productivity but also volumes, physical and carbon footprint, flexibility, investment cost, staff skills and earlier investments.
- Pure laser welding of aluminium could not fully avoid cracking (nor an oscillating beam). But with more work……
- Pure laser welding of material combinations with Novelis Fusion material present received no cracks, but the joint strength did not receive the wished values, more work needed to optimise.



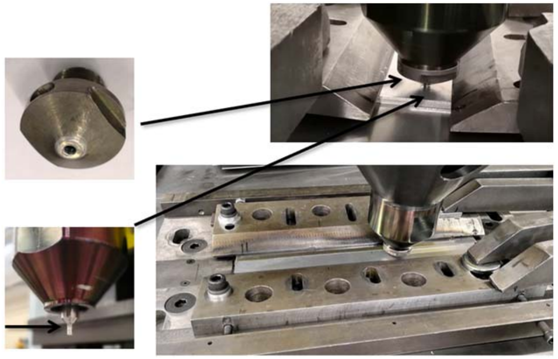


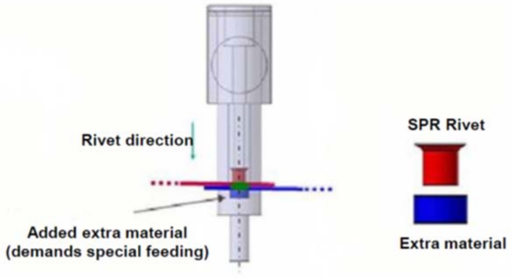


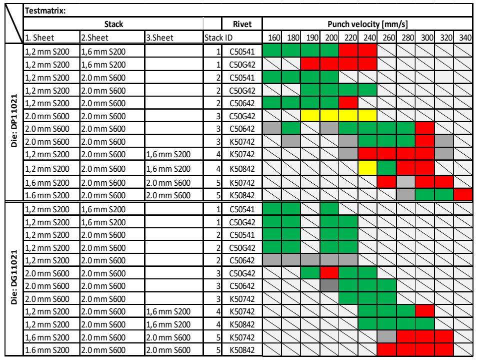
- Advanced MIG-welding could reduce material softening in the HAZ (heat-affected zone). For most cases, acceptable results.

Conclusions

- FSW achieved zero HAZ softening in aluminium joints. Tool geometry and suitable level of stirring very important.
  FSW Stationary shoulder method had even less heat but needed extra strong tool to manage stirring the 7XXX aluminium alloy.
  Clamping extremely essential and need to be solved from case to case (as tool geometry).



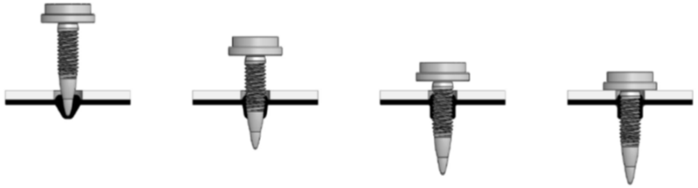


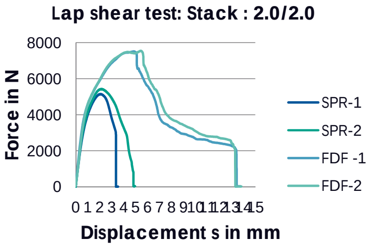


	Testmatrix:															
	Stack				Rivet	Punch velocity [mm/s]										
	1. Sheet	2.Sheet	3.Sheet	Stack ID		160	180	190	200	220	240	260	280	300	320	340
Die: DP11021	1,2 mm S200	1,6 mm S200		1	C50541	🟩	🟩	🟩	🟩	🟥	🟥	╲	╲	╲	╲	╲
	1,2 mm S200	1,6 mm S200		1	C50G42	╲	╲	🟥	🟥	🟥	🟥	╲	╲	╲	╲	╲
	1,2 mm S200	2.0 mm S600		2	C50541	🟩	🟩	🟩	🟩	╲	╲	╲	╲	╲	╲	╲
	1,2 mm S200	2.0 mm S600		2	C50G42	╲	╲	🟩	🟩	🟩	🟩	╲	╲	╲	╲	╲
	1,2 mm S200	2.0 mm S600		2	C50642	🟩	🟩	🟩	🟩	🟥	╲	╲	╲	╲	╲	╲
	2.0 mm S600	2.0 mm S600		3	C50G42	╲	╲	🟨	🟨	🟨	🟨	╲	╲	╲	╲	╲
	2.0 mm S600	2.0 mm S600		3	C50642	▒	🟩	╲	▒	🟩	🟩	🟩	🟩	🟥	╲	╲
	2.0 mm S600	2.0 mm S600		3	K50742	╲	▒	╲	╲	▒	🟩	🟩	🟩	🟥	▒	╲
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50742	╲	╲	╲	╲	▒	🟥	🟥	🟥	🟥	▒	╲
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50842	╲	╲	╲	╲	╲	🟨	🟩	🟥	🟥	╲	╲
	1,6 mm S200	2.0 mm S600	2.0 mm S600	5	K50742	╲	╲	╲	╲	╲	╲	🟥	▒	🟥	🟥	╲
	1.6 mm S200	2.0 mm S600	2.0 mm S600	5	K50842	╲	╲	╲	╲	╲	╲	╲	▒	🟩	🟩	🟥
Die: DG11021	1,2 mm S200	1,6 mm S200		1	C50541	🟩	🟩	╲	🟩	╲	╲	╲	╲	╲	╲	╲
	1,2 mm S200	1,6 mm S200		1	C50G42	🟩	🟩	╲	🟩	🟩	╲	╲	╲	╲	╲	╲
	1,2 mm S200	2.0 mm S600		2	C50541	🟩	🟩	╲	🟩	🟩	╲	╲	╲	╲	╲	╲
	1,2 mm S200	2.0 mm S600		2	C50G42	🟩	🟩	╲	🟩	🟩	╲	╲	╲	╲	╲	╲
	1,2 mm S200	2.0 mm S600		2	C50642	▒	▒	▒	▒	▒	╲	╲	╲	╲	╲	╲
	2.0 mm S600	2.0 mm S600		3	C50G42	╲	╲	🟩	🟥	🟩	🟩	╲	╲	╲	╲	╲
	2.0 mm S600	2.0 mm S600		3	C50642	╲	╲	╲	▒	🟩	🟩	🟩	╲	╲	╲	╲
	2.0 mm S600	2.0 mm S600		3	K50742	╲	╲	╲	╲	🟩	🟩	🟩	╲	╲	╲	╲
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50742	╲	╲	╲	╲	╲	🟩	🟩	🟩	🟥	╲	╲
	1,2 mm S200	2.0 mm S600	1,6 mm S200	4	K50842	╲	╲	╲	╲	╲	🟩	🟩	🟩	🟩	╲	╲
	1,6 mm S200	2.0 mm S600	2.0 mm S600	5	K50742	╲	╲	╲	╲	╲	╲	▒	🟥	🟥	🟥	╲
	1.6 mm S200	2.0 mm S600	2.0 mm S600	5	K50842	╲	╲	╲	╲	╲	╲	🟥	🟥	🟥	🟥	╲

- For SPR, suitable material stack combinations and die and rivet geometries were identified. Demanding material combinations can utilize the PER method (Plug-Element-Riveting), which enable otherwise impossible material combinations to be joined.

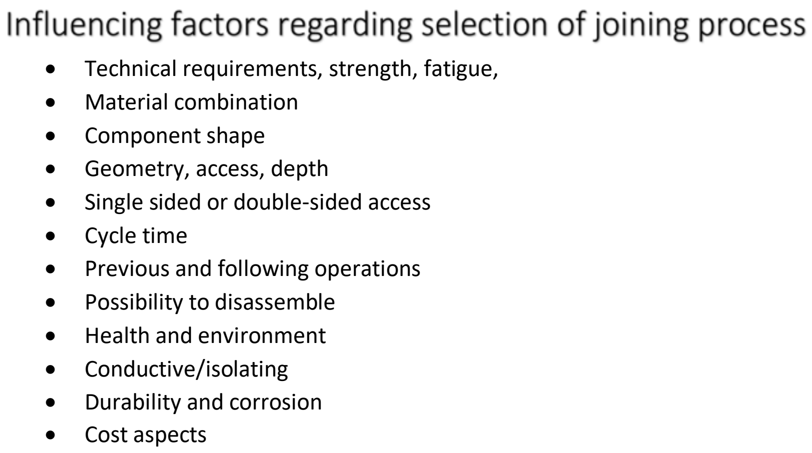
- FDF received higher shear tensile joint strength than SPR and is removable and resettable (but has higher element weight).
  Both FDF and SPR are successfully used in hybrid joining with adhesives.





Conclusions

- **RSW achieved good results for evaluated thin aluminium material combinations and a lightweight hood can be realized.**
- **Adhesives received successful results when correct pre-preparation was applied. A lightweight car floor can be realized. Adhesives (or advanced MIG-welding) will also be used for new and lighter crash management systems.**
- **Hybrid joining methods FEW & REW: FEW received better shear strength results and can join very different material types. A new version (SRE) is available with a lighter fastening element, although not the same joint strength. FEW will be utilized when other options are less suitable, and REW will find its applications, especially where an SPR method is already utilized on a component and extra parts mounting is needed. FEW and REW can be used with adhesives.**



Influencing factors regarding selection of joining process

- Technical requirements, strength, fatigue,
- Material combination
- Component shape
- Geometry, access, depth
- Single sided or double-sided access
- Cycle time
- Previous and following operations
- Possibility to disassemble
- Health and environment
- Conductive/isolating
- Durability and corrosion
- Cost aspects

Joakim Hedegard, Swerim, Isafjordsgatan 28A, 16440 Kista, Sweden	+46 70 461 0334	Joakim.hedegard@swerim.se
Jan Skogsmo, RISE IVF, Argongatan 30, 43153 Mölndal, Sweden	+46 70 780 6042	jan.skogsmo@ri.se