



User committee meeting project “HYBRISONIC”

Ultrasonic supported processing of hybrid materials

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Content

- ▶ Joining strategies
- ▶ Joining experiments on samples with non-displaced core
- ▶ Displacement of the plastic core
- ▶ Joining experiments on samples with displaced core

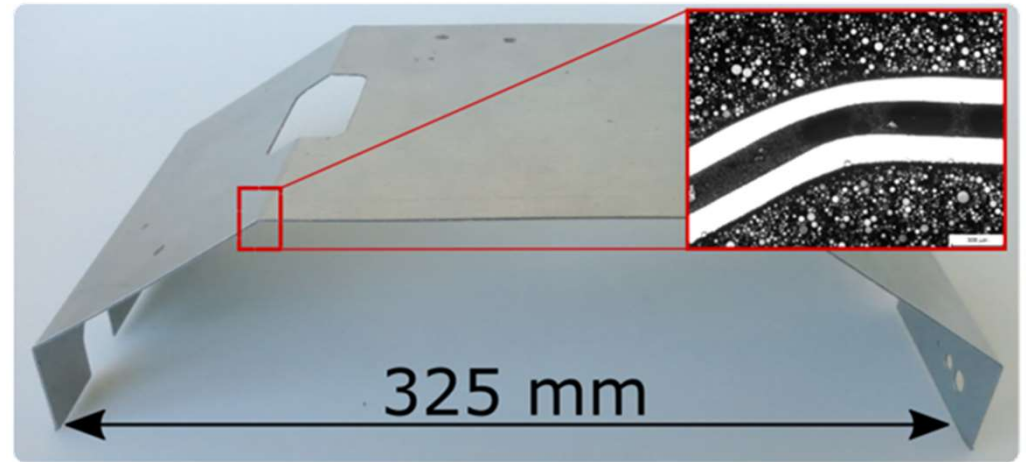
Goal - Experimental data

Goals

- ▶ Joining of metal-polymer composites (**MPC**) to conventional aluminium sheets
- ▶ Feasibility investigation

Experimental data

- ▶ MPC :
 - ▶ Hylite
 - ▶ thickness : 1,2 mm
 - ▶ EN AW-5182 MPC skin sheets



Modulus of elasticity [GPa]	Yield strength [MPa]	Tensile strength [MPa]	Service temperature [°C]
70,0	> 320,0	> 380,0	-30,0 - 120,0

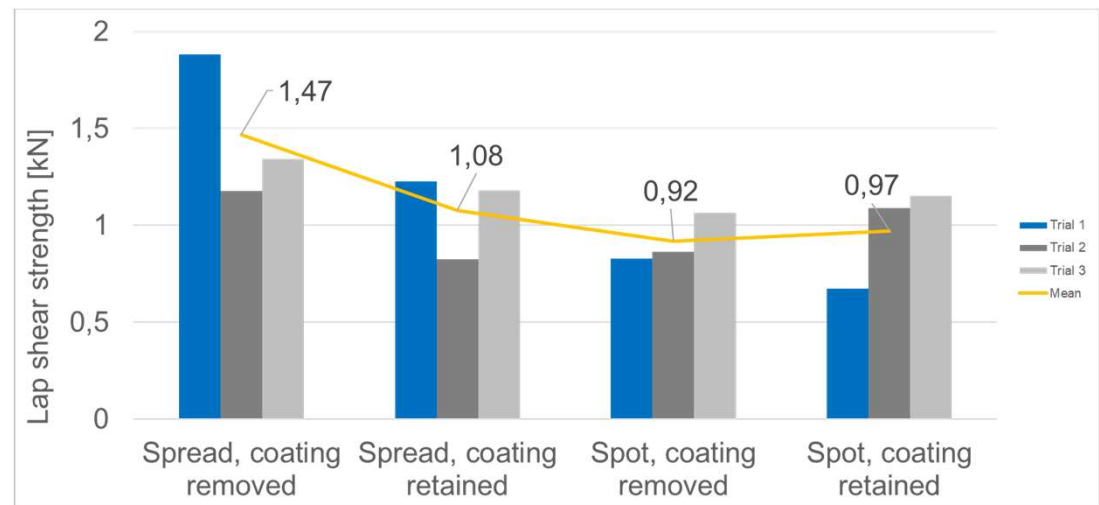
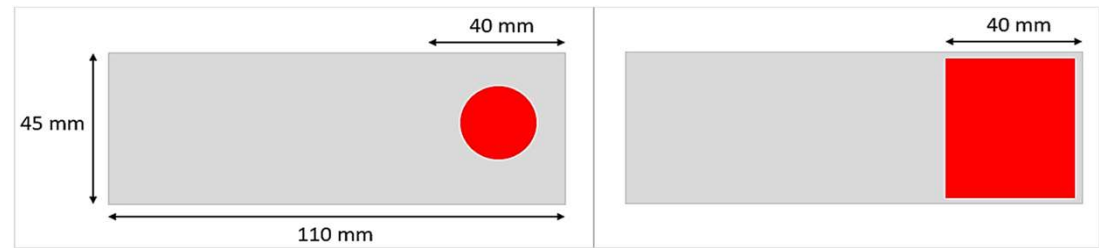
- ▶ Conventional aluminium sheet :
 - ▶ EN AW-6082-T6
 - ▶ Thickness : 1,0 & 1,5 mm

Conventional joining processes

Adhesive bonding

- ▶ Requires pre-treatment: more elaborate compared to bolting, involving surface contamination removal, uniform application of the adhesive, etc.
- ▶ Uniform application of adhesive :
lap shear strength $\approx 1,90$ kN
- ▶ Spot-wise application of adhesive :
lap shear strength $\approx 0,95$ kN

	Material	Thickness (mm)
Upper sheet	Hylite® MPC	1,2
Lower sheet	EN AW-6082-T6	1,5

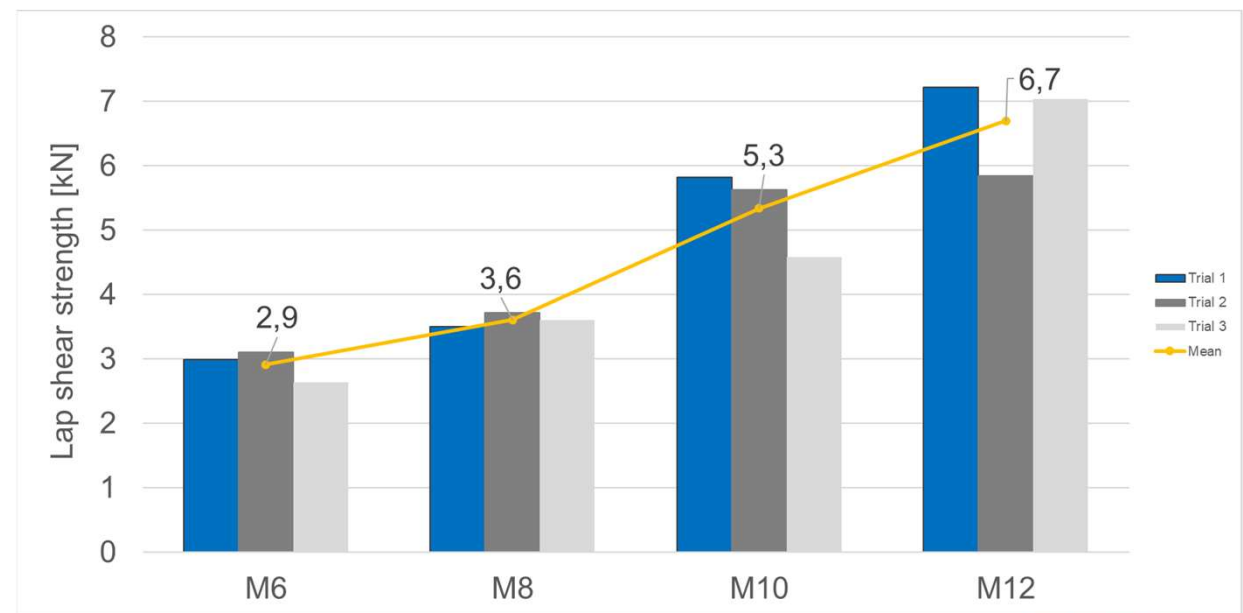
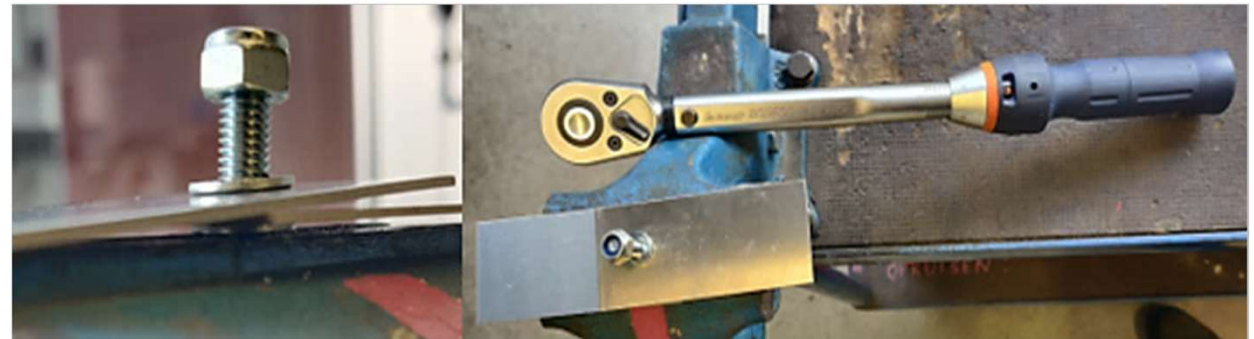


Conventional joining processes

Bolted connections

- ▶ Metric sizes : M6 → M12
- ▶ Lap shear strength ↑
- ▶ Advantages:
 - ▶ Accessible machinery
 - ▶ Low complexity
- ▶ Disadvantages:
 - ▶ Weight penalty
 - ▶ Protruding parts
 - ▶ Requires several operations (drilling, applying torque, etc)

	Material	Thickness (mm)
Upper sheet	Hylite® MPC	1,2
Lower sheet	EN AW-6082-T6	1,5

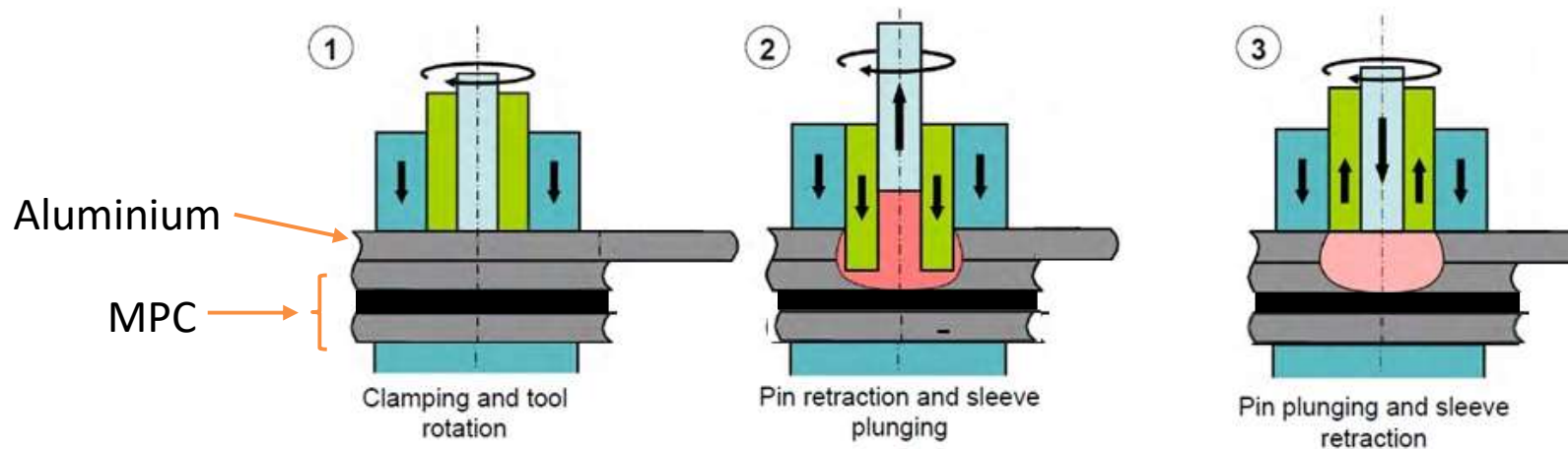


Innovative joining processes

Classifications	I.a)	I.b)	I.c)	I.d)	I.e)	I.f)	II.a)	II. b)	II.c)	II.d)	III. a)	III. b)	III. c)	III. d)	III. e)	III. f)	III. g)	IV. a)	IV. b)	Total
Electric resistance welding																				
Resistance pot welding	3	1	5	3	1	5	3	3	3	5	5	3	5	5	5	5	5	3	3	71
Resistance seam welding	3	1	5	3	1	5	3	3	3	3	3	1	3	5	5	5	5	3	3	63
Resistance element welding	5	5	5	5	1	5	3	5	3	3	3	3	3	5	5	5	1	3	3	71
Resistance stud welding	5	3	3	5	1	5	3	3	5	3	5	5	5	3	5	3	1	3	3	69
Induction welding	5	3	5	1	1	3	3	3	3	5	3	3	1	1	1	3	3	3	3	53
Beam welding																				
Electron beam welding	5	3	3	3	3	3	3	3	3	3	1	1	1	5	1	5	5	3	1	55
Laser beam welding	5	3	3	3	3	3	3	3	3	3	1	1	3	5	3	5	5	3	1	59
Arc welding																				
Gas metal arc welding	3	1	1	5	3	1	1	3	1	1	5	5	1	5	1	1	1	1	1	41
Solid-state welding																				
Friction stir welding	3	5	5	3	1	5	5	5	5	5	1	1	3	5	3	5	5	5	5	73
Friction stir spot welding	3	5	5	5	1	5	5	5	5	3	3	3	3	5	3	5	5	5	5	79
Refill friction stir spot welding	3	5	5	5	1	5	5	5	5	5	3	3	3	5	3	5	5	5	5	81
Ultrasonic welding	3	5	5	5	1	5	5	5	5	3	5	3	5	5	5	3	5	5	5	83

Joining strategies

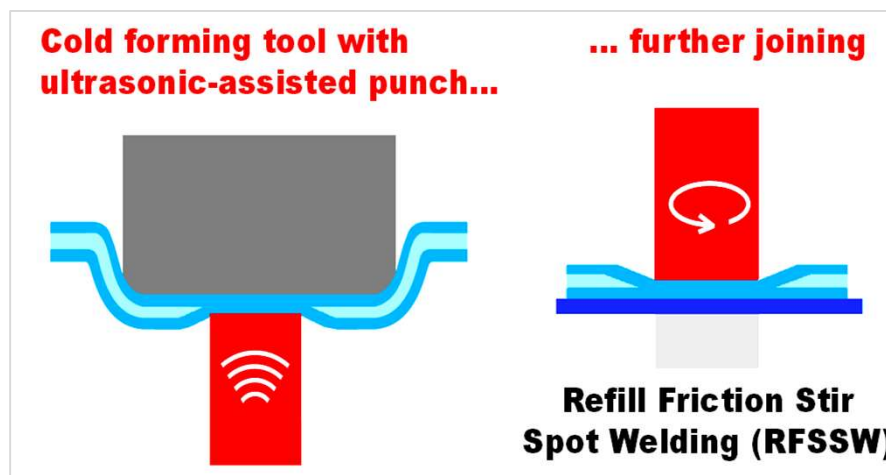
1. Joining of aluminium sheets to MPCs with non-displaced core :



Joining with :

- Friction stir spot welding (FSSW)
- Refill friction stir spot welding (RFSSW)
- Ultrasonic welding (USW)

2. Joining of aluminium sheets to MPCs with displaced core : Two-step approach



Displacement with :

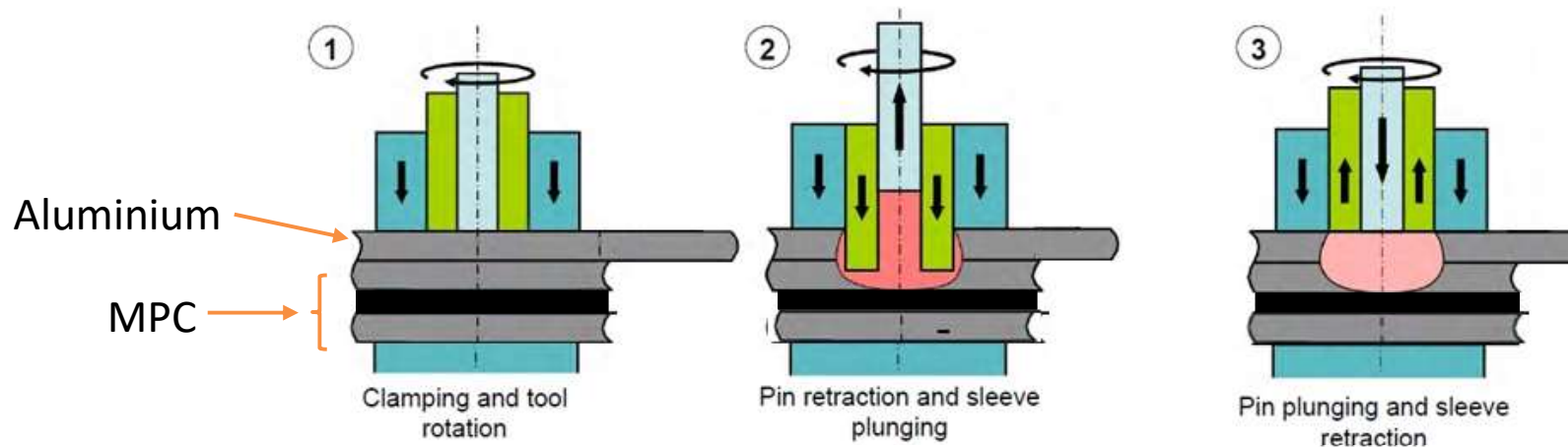
- Refill friction stir spot process
- Modified friction stir spot tool
- Ultrasonic vibrations

Joining with :

- Refill friction stir spot welding (RFSSW)
- Friction stir spot welding (FSSW)
- Ultrasonic welding (USW)

Joining strategies

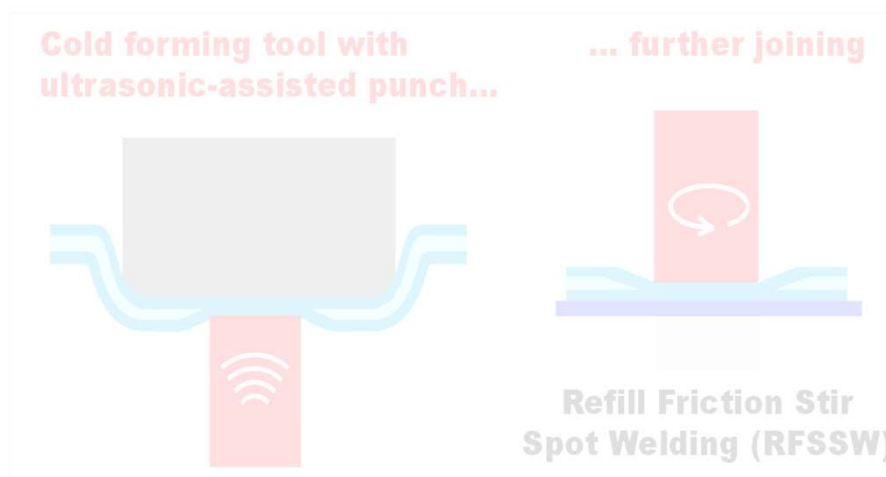
1. Joining of aluminium sheets to MPCs with non-displaced core :



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Displacement with :

- Refill friction stir spot process
- Modified friction stir spot tool
- Ultrasonic vibrations

Joining with :

- Refill friction stir spot welding (RFSSW)
- Friction stir spot welding (FSSW)
- Ultrasonic welding (USW)

Joining experiments on samples with non-displaced core

Processes

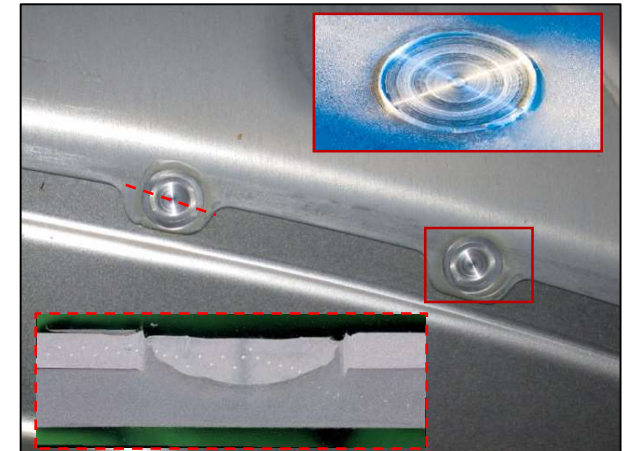
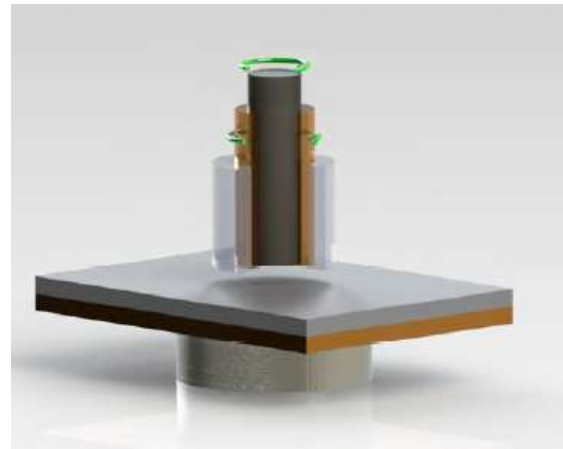
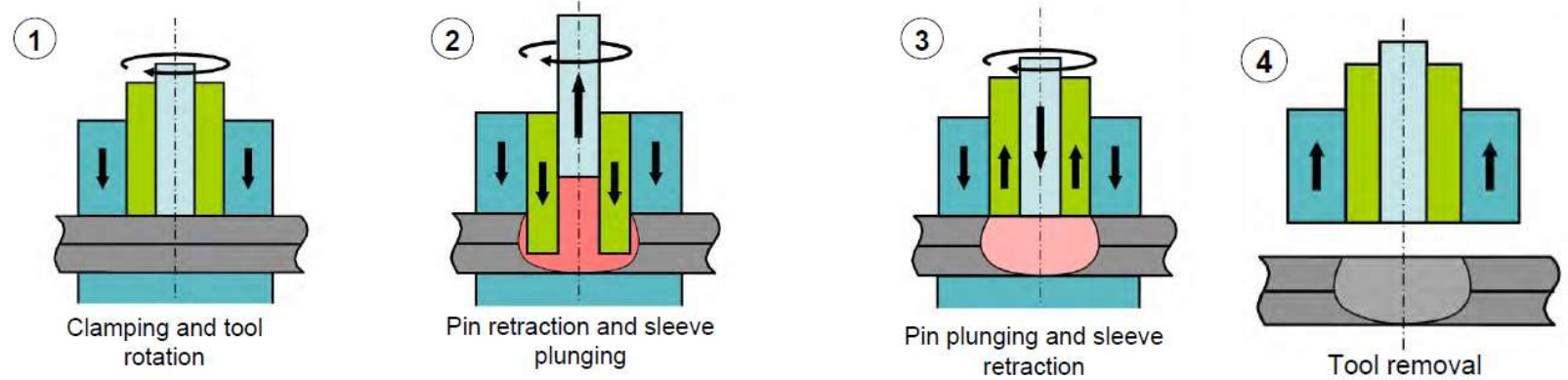
- ▶ Refill friction stir spot welding (RFSSW) of aluminium sheets to the MPC skin sheets
- ▶ Friction stir spot welding (FSSW)
- ▶ Ultrasonic welding (USW)
- ▶ Refill friction stir spot welding (RFSSW) :
 - ▶ Single step, multi-plunge variant
 - ▶ Multi-step, single-plunge variant

Joining experiments on samples with non-displaced core

Refill friction stir spot welding (RFSSW)

Stages:

- ▶ Clamping
- ▶ Lowering
- ▶ Softening
- ▶ Stirring
- ▶ Mixing
- ▶ Keyhole refilling
- ▶ Retraction
- ▶ Releasing

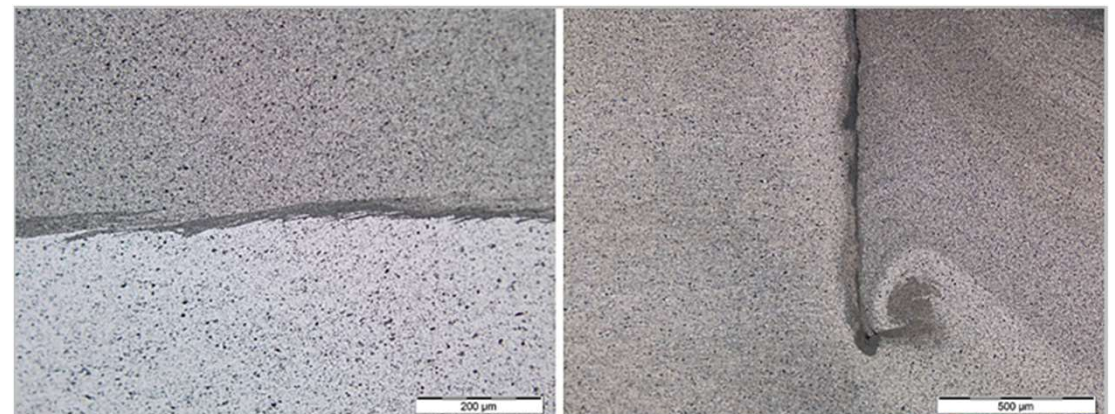
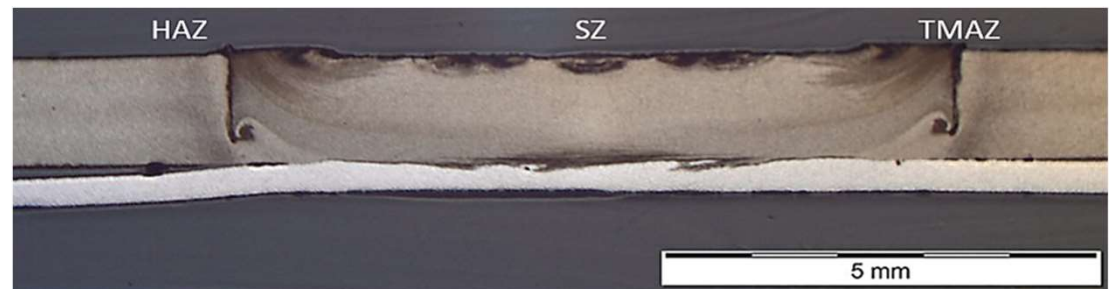
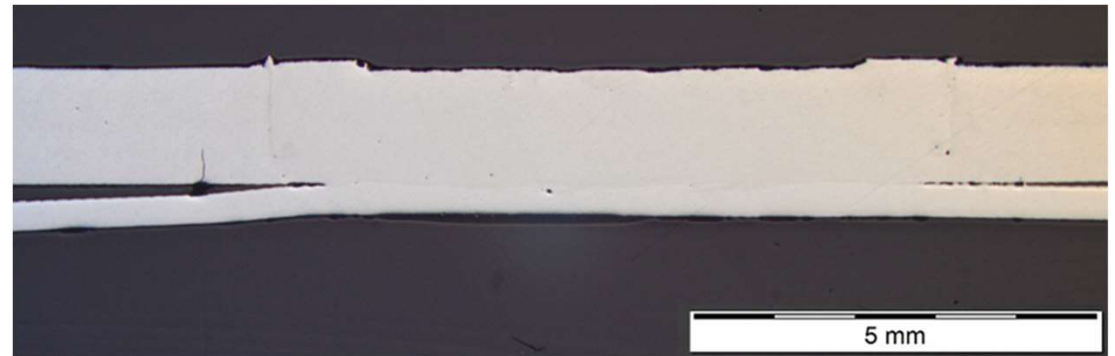


Joining experiments on samples with non-displaced core

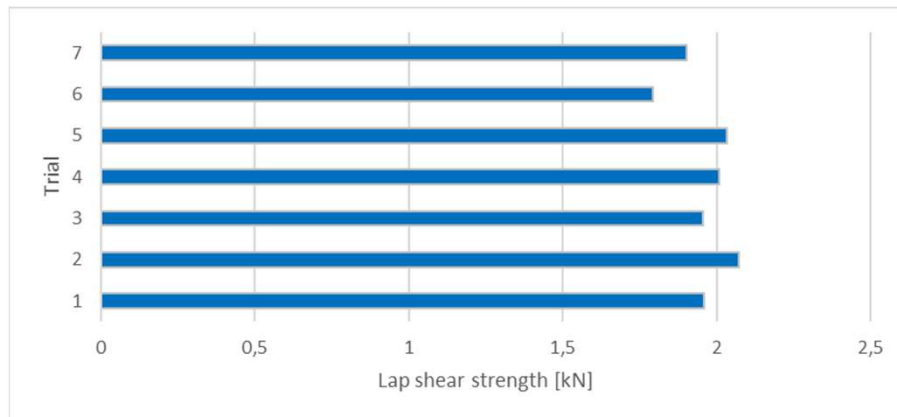
Refill friction stir spot welding

- ▶ Weldability of aluminium sheets to the MPC skin sheets
- ▶ Welding thick to thin aluminium sheets : feasible
- ▶ Lap shear strength ≈ 2 kN

	Material	Thickness (mm)
Upper sheet	EN AW-6082-T6	1,5
Lower sheet	EN AW-5182	0,3

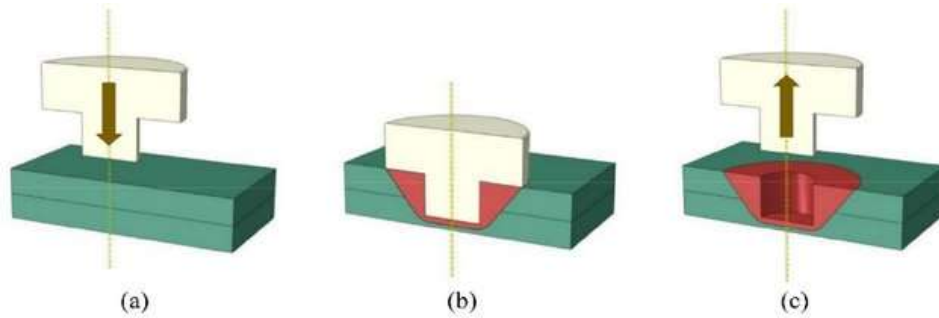


Lap shear strength

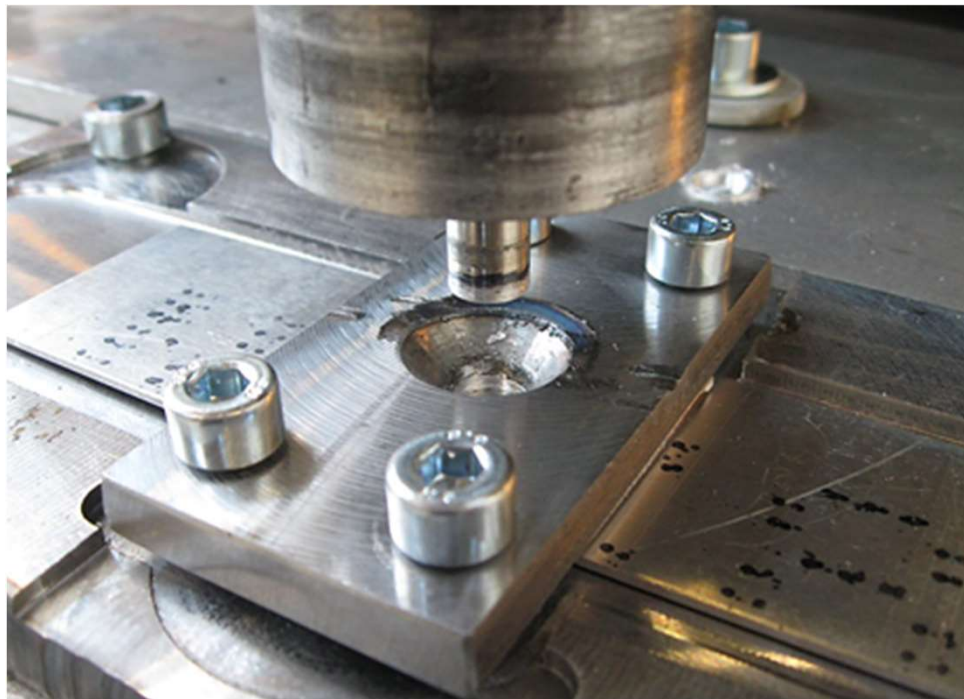
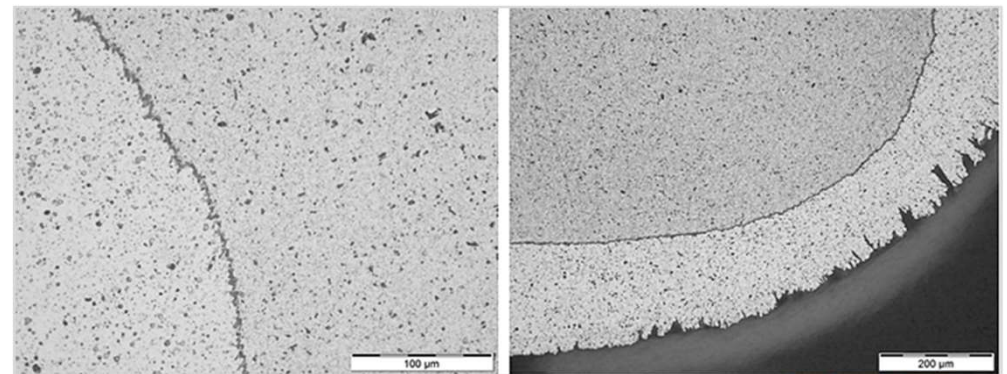
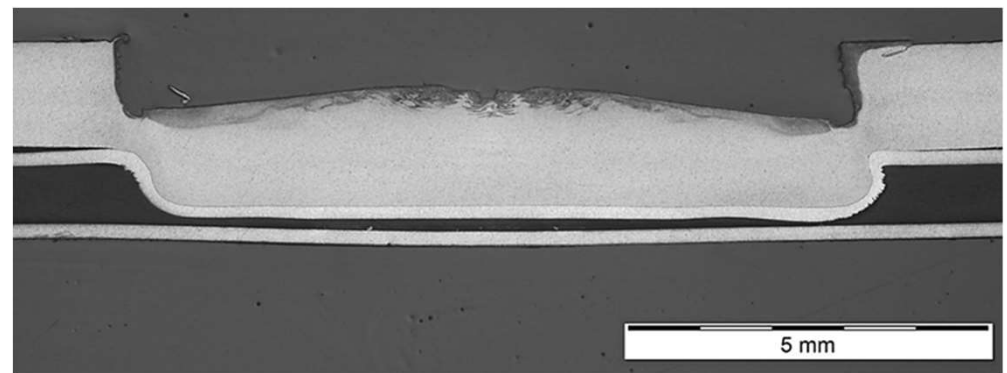
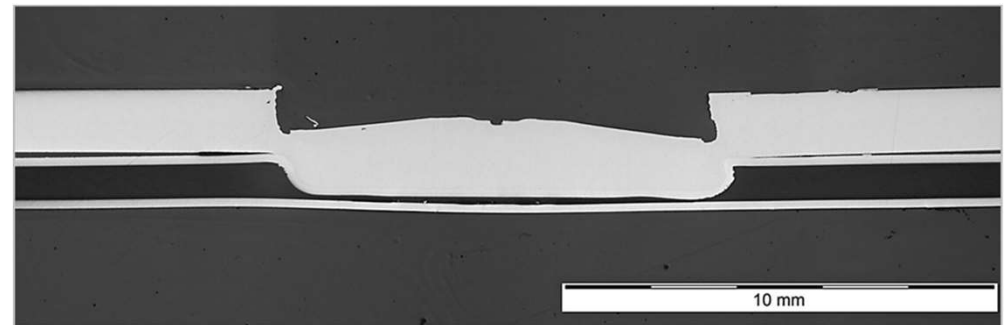


Joining experiments on samples with non-displaced core

Friction stir spot welding



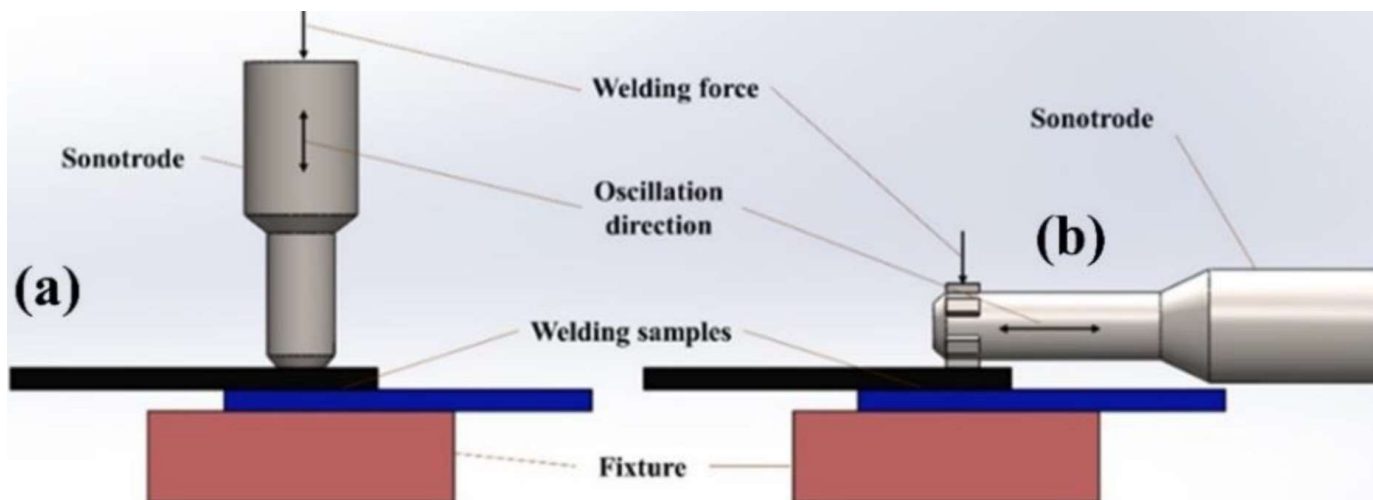
	Material	Thickness (mm)
Upper sheet	EN AW-6082-T6	1,5
Lower sheet	Hylite®	1,2



Joining experiments on samples with non-displaced core

Ultrasonic welding (USW)

- ▶ High energy ultrasonic waves
- ▶ High frequency mechanical motion
- ▶ Temperature \uparrow

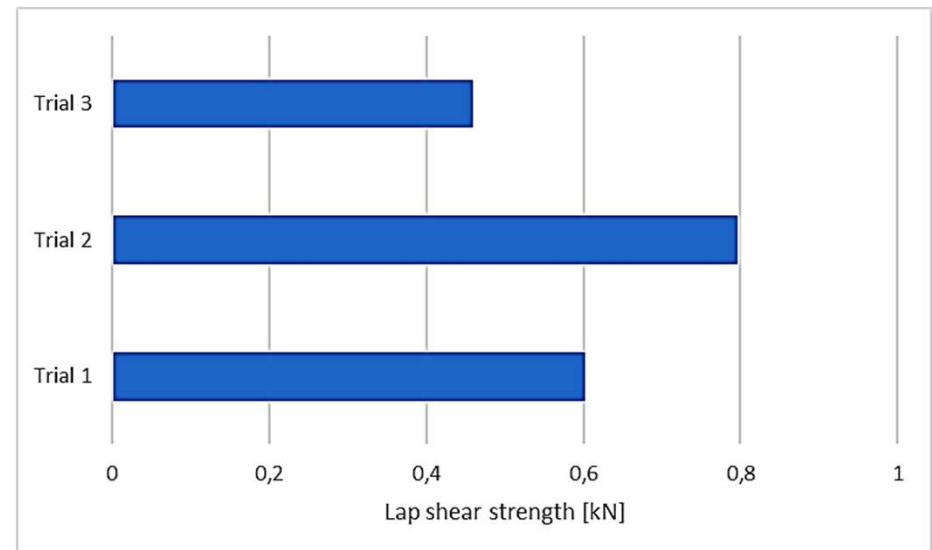
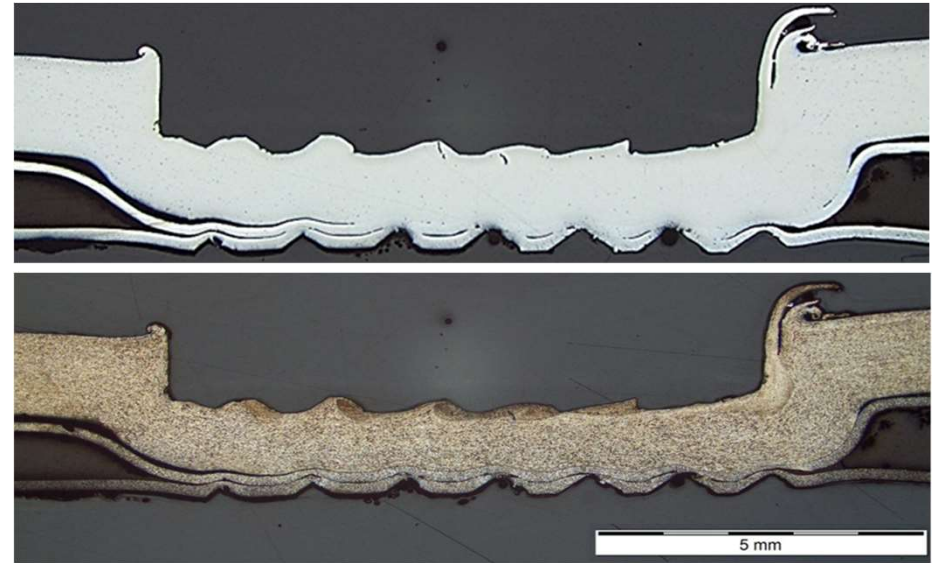


Joining experiments on samples with non-displaced core

Ultrasonic welding

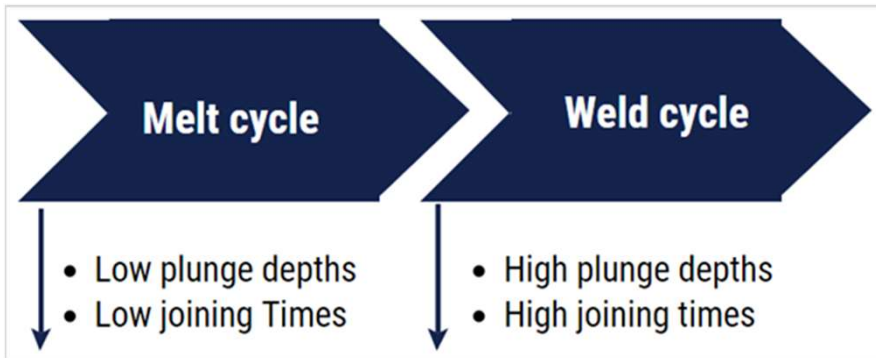
- ▶ Ultrasonic energy is sufficient to displace the plastic core and to create a welded area
- ▶ Force on the sonotrode is necessary to expel the plasticized polypropylene from the joint area
- ▶ Long welding times are required and high pressure to obtain sufficient interfacial contact
- ▶ Due to the high clamping forces, fractures can appear within the welded area

	Material	Thickness (mm)
Upper sheet	EN AW-6082-T6	1,5
Lower sheet	Hylite®	1,2

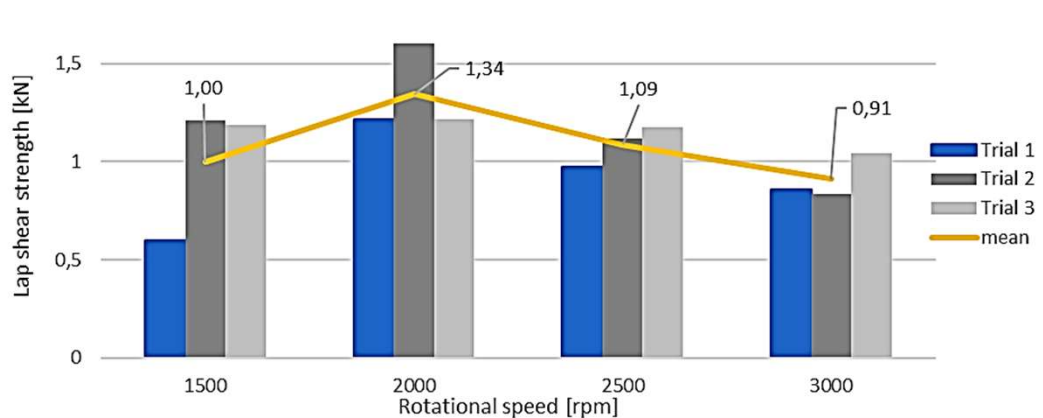
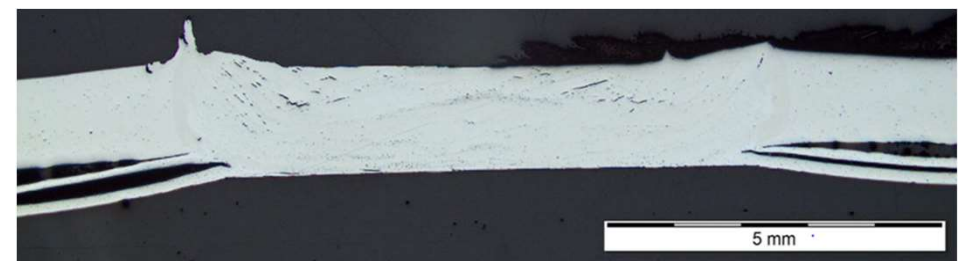


Joining experiments on samples with non-displaced core

Refill friction stir spot welding



	Material	Thickness (mm)
Upper sheet	EN AW-6082-T6	1,5
Lower sheet	Hylite®	1,2



Conclusions

- ▶ Good weld quality (no incomplete refill, unbonded regions, excessive deformation, etc.)
- ▶ Bending of the sheets

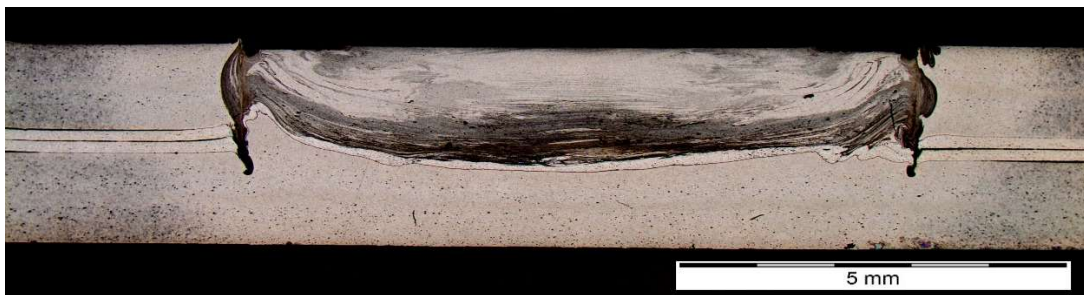
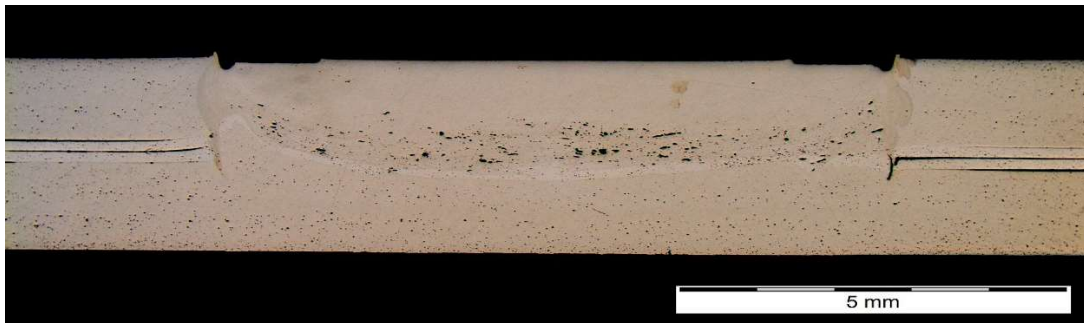
Joining experiments on samples with non-displaced core

RFSSW – With additional sheet

- ▶ Configuration : **Alu (top & bottom)** + MPC (mid)



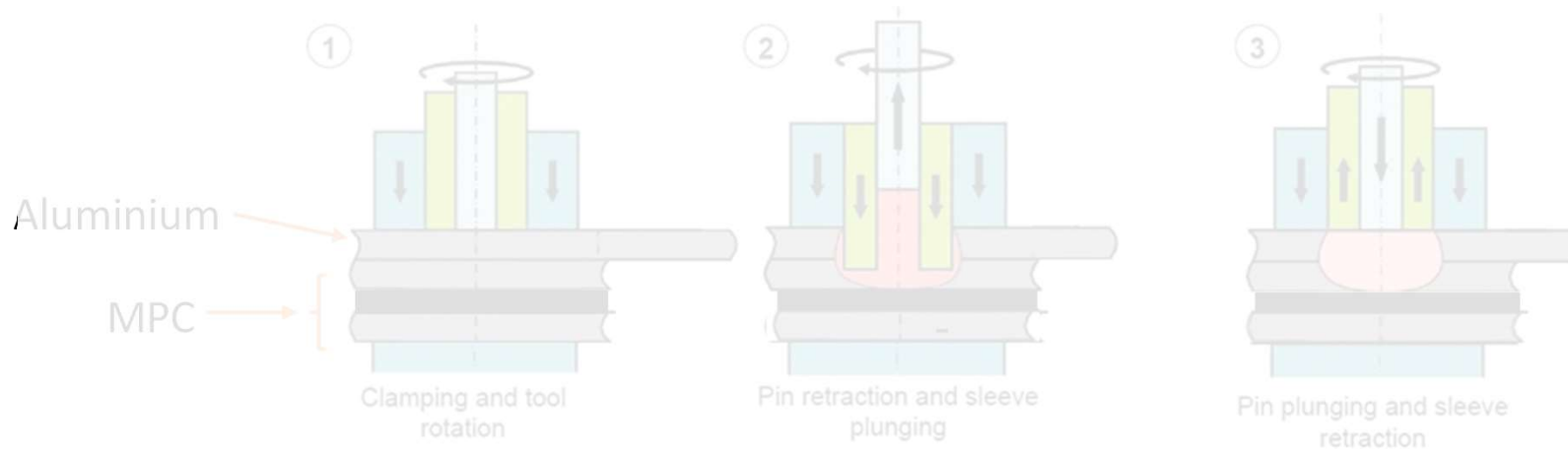
	Material	Thickness (mm)
Upper sheet	EN AW-6082-T6	1,5
Middle sheet	Hylite®	1,2
Lower sheet	EN AW-6082-T6	1,5



- ▶ Lap shear strength \approx 3 kN

Joining strategies

1. Joining of aluminium sheets to MPCs with undisplaced core



Joining with :

- Refill friction stir spot welding (RFSSW)
- Ultrasonic welding (USW)

2. Joining of aluminium sheets to MPCs with displaced core : Two-step approach



Displacement with :

- Refill friction stir spot process
- Modified friction stir spot tool
- Ultrasonic vibrations

Joining with :

- Refill friction stir spot welding (RFSSW)
- Friction stir spot welding (FSSW)
- Ultrasonic welding (USW)

Joining experiments on samples with displaced core

Displacement of the plastic core

- ▶ Refill friction stir process – Pin plunge
- ▶ Refill friction stir process – Sleeve plunge
- ▶ Refill friction stir process – Pin-Sleeve plunge
- ▶ Ultrasonic vibrations
- ▶ Frictional heat

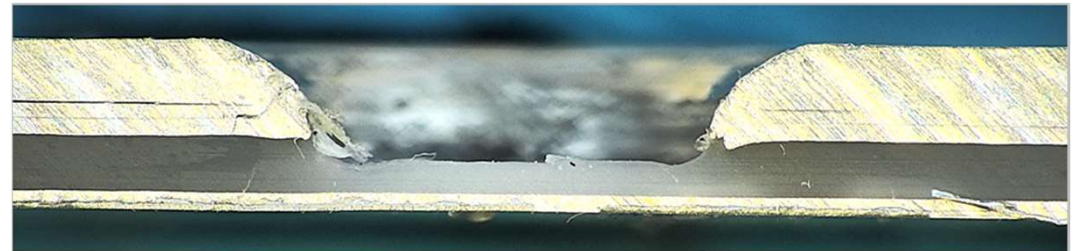
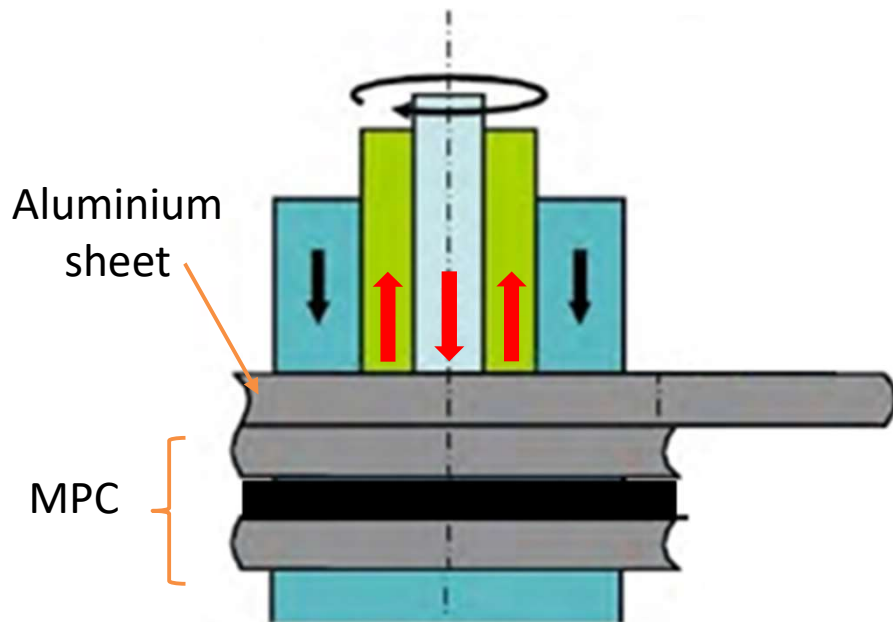
Joining of samples with displaced core

- ▶ Refill friction stir welding process - Sleeve plunge variant
- ▶ Refill friction stir welding process – Pin plunge variant
- ▶ Ultrasonic welding

Joining experiments on samples with displaced core

Displacement of the plastic core

- ▶ RFSSW – Pin plunge



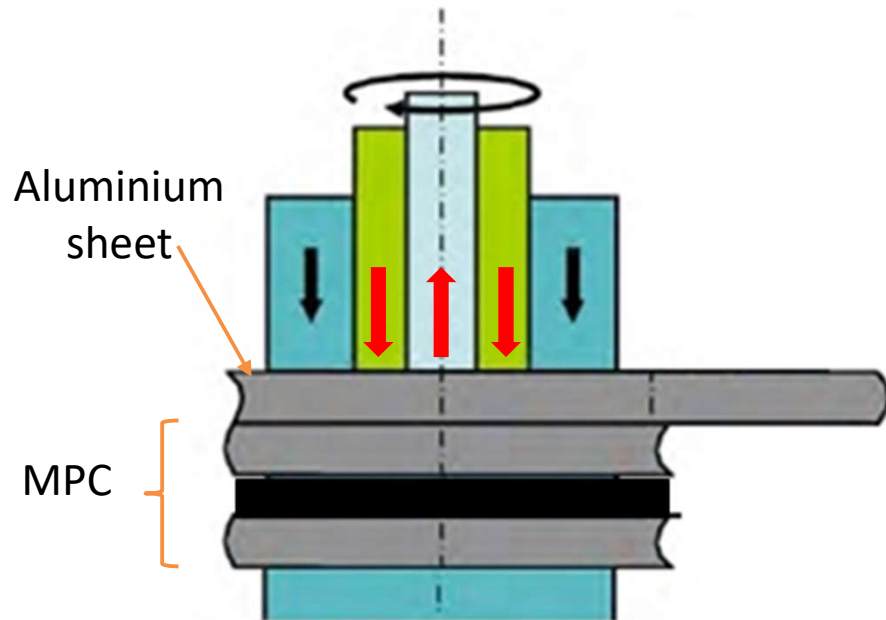
Conclusions

- ▶ prone to top-sheet perforation
- ▶ pin-plunge method not applicable

Joining experiments on samples with displaced core

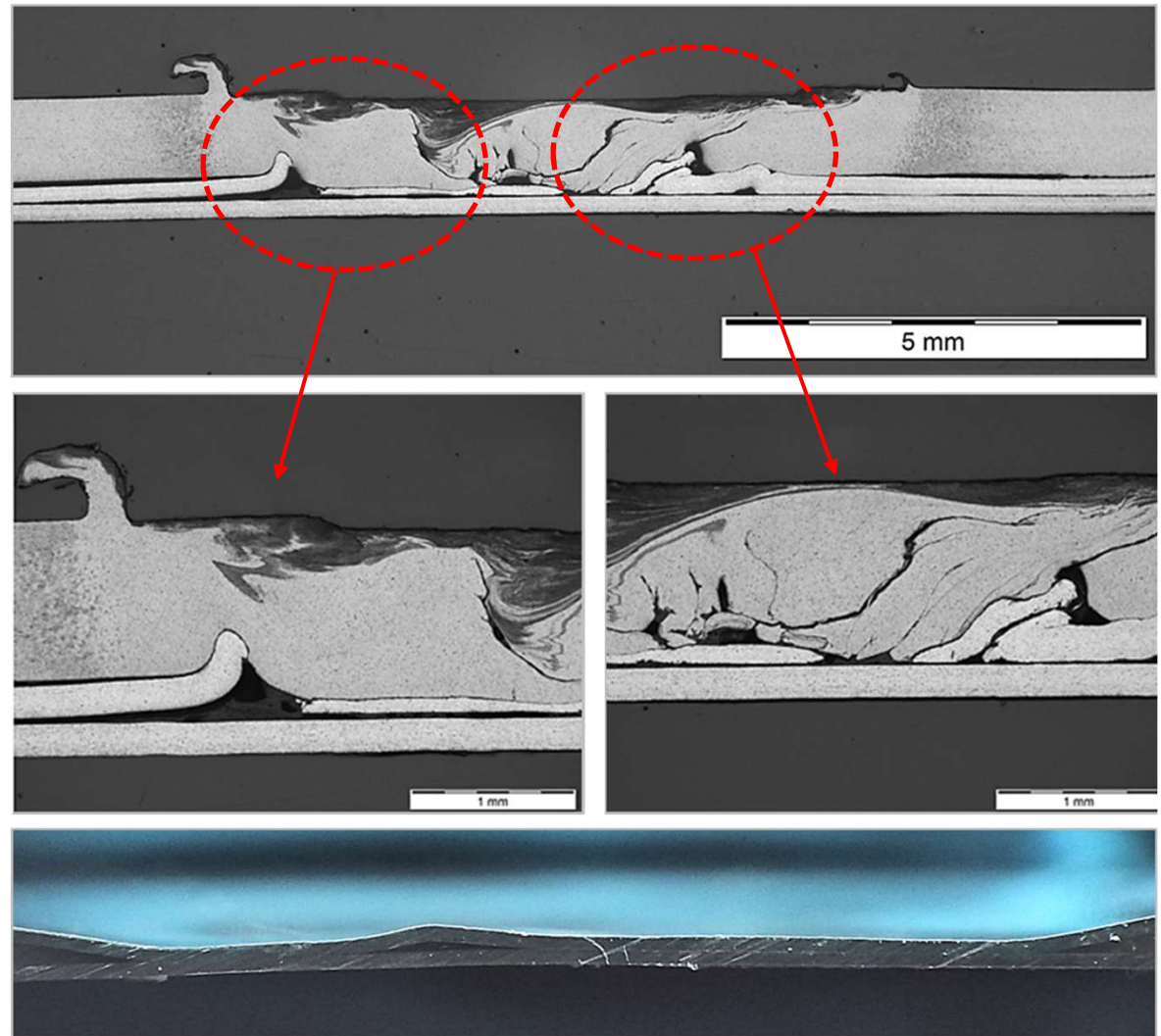
Displacement of the plastic core

- ▶ RFSSW – Sleeve plunge



Conclusions

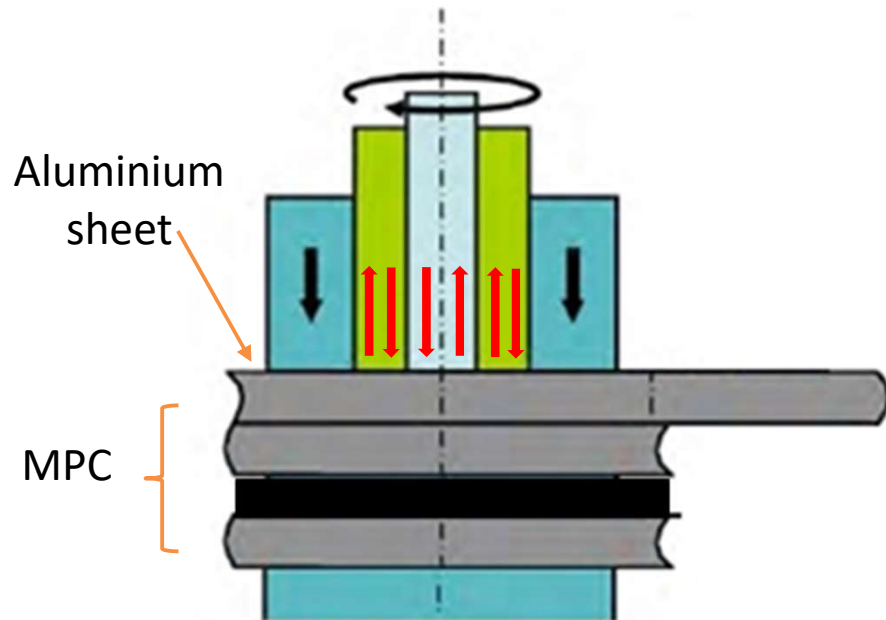
- ▶ Top sheet perforation is prevented
- ▶ Plastic core is displaced
- ▶ Risk of deformation/cracking of the MPC skin



Joining experiments on samples with displaced core

Displacement of the plastic core

- ▶ RFSSW – Pin-Sleeve plunge



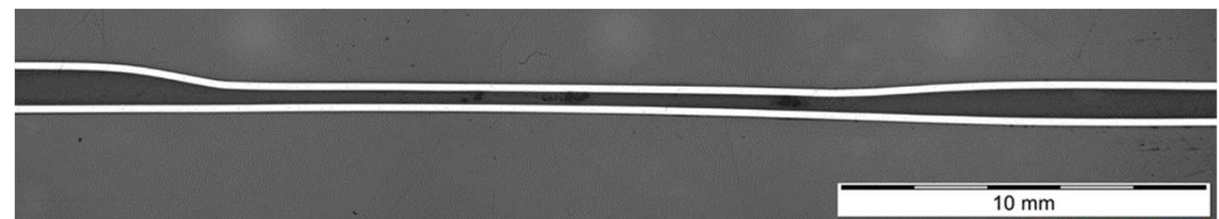
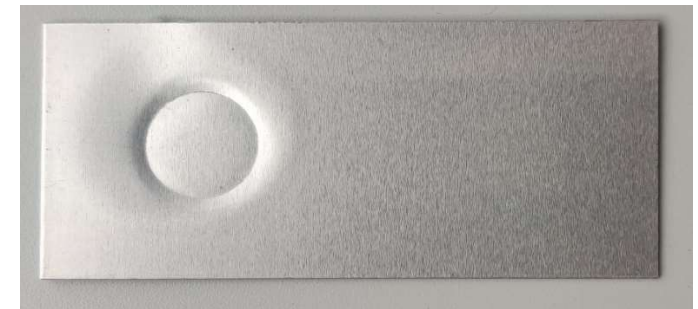
Conclusions

- ▶ By performing several plunge cycles one after the other : sufficient heat is generated to :
 - ▶ displace the plastic core
 - ▶ to weld both materials
- ▶ Welding can be prevented by using a thicker upper joining partner
- ▶ Further parameter optimisation necessary

Joining experiments on samples with displaced core

Displacement of the plastic core

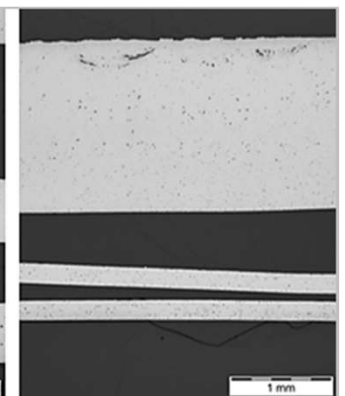
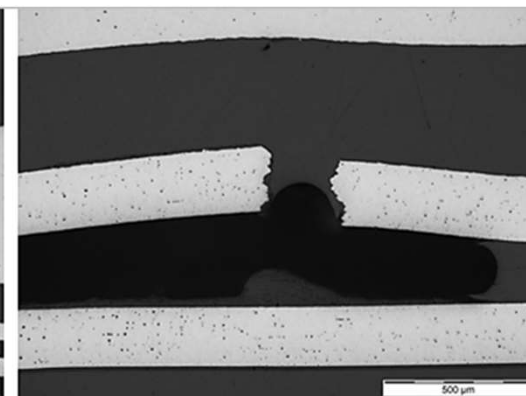
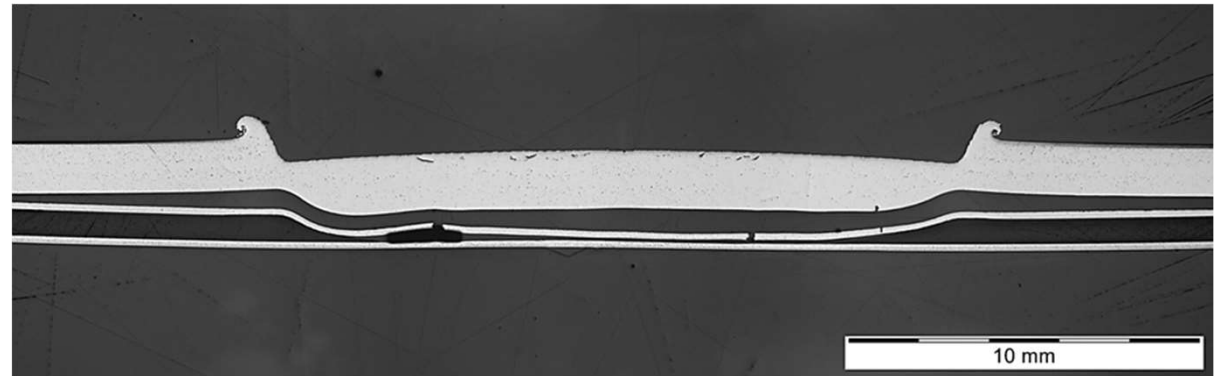
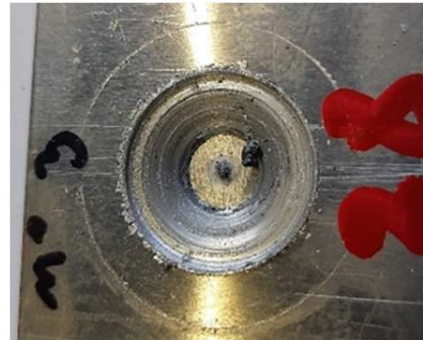
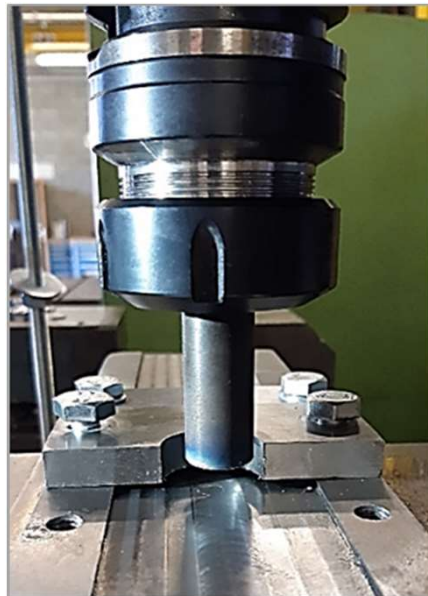
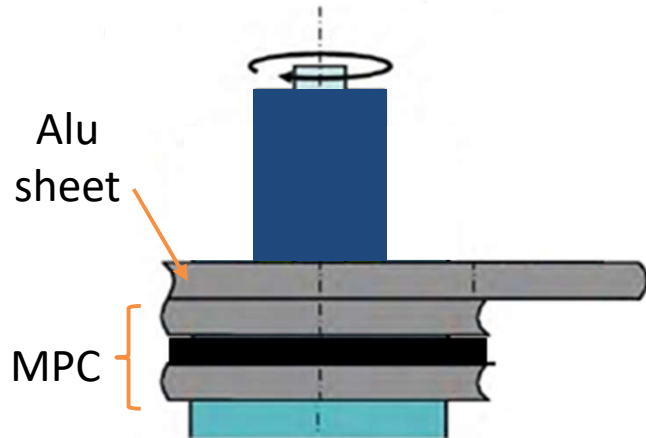
- ▶ Ultrasonic vibrations
- ▶ Conclusions
 - ▶ Displacement of the core by ultrasonic waves is possible
 - ▶ Most significant parameters : shape of the sonotrode, process time, amplitude but also the sonotrode temperature
 - ▶ After displacement, metallic cover skin sheets are highly plastically deformed, both by indentation of the sonotrode and the polymer flow behaviour during liquefaction.



Joining experiments on samples with displaced core

Displacement of the plastic core

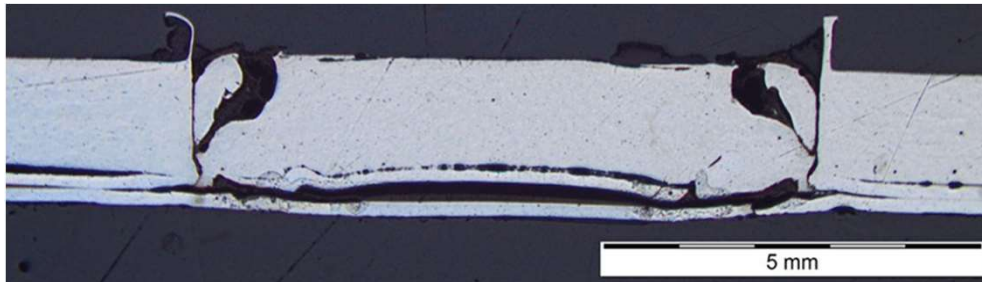
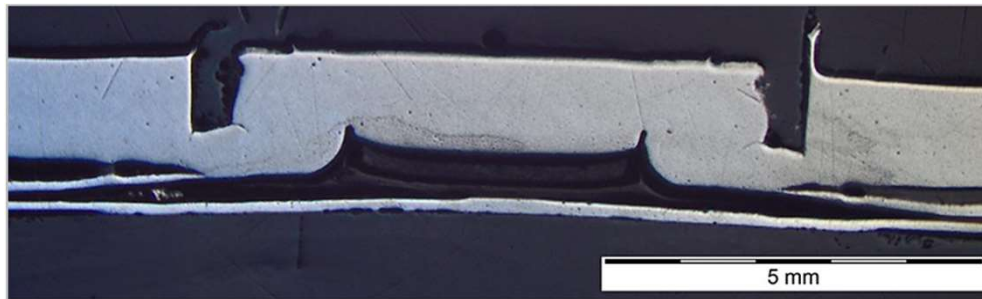
- ▶ Friction stir spot tool



Joining experiments on samples with displaced core

RFSSW - Sleeve plunge variant

	Material	Thickness (mm)
Upper sheet	EN AW-6082-T6	1,5
Lower sheet	Hylite®	1,2



▶ Conclusions :

- ▶ Weak interconnections
- ▶ Large plastic deformation
- ▶ Incomplete filling pattern

RFSSW - Pin plunge variant



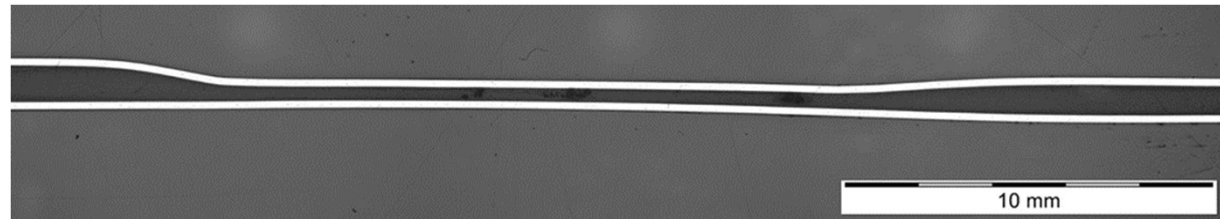
▶ Conclusions :

- ▶ Retraction time : most decisive parameter to overcome the incomplete refilling defect
- ▶ Awareness must be brought to the plastic deformation of the (fragile) joining components.

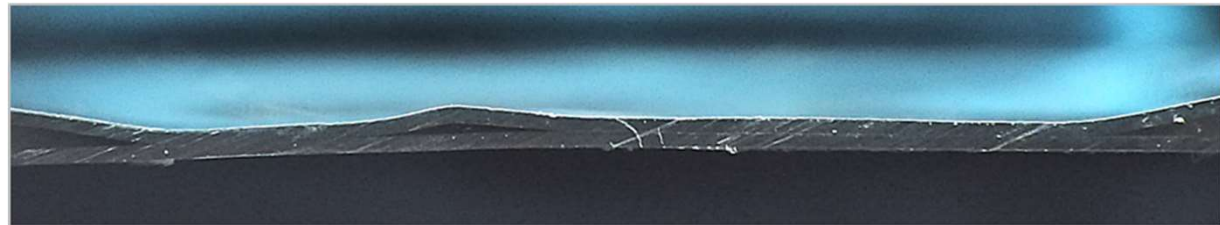
Conclusions

- ▶ Displacement of the plastic core possible using :

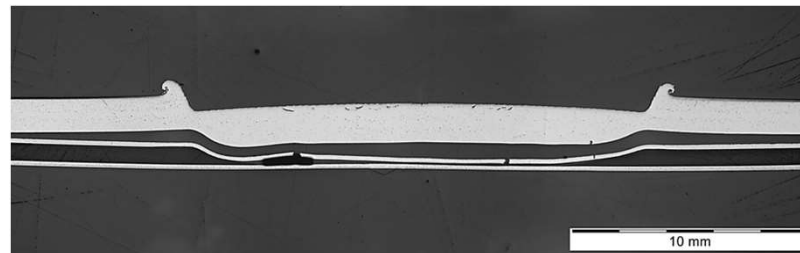
Ultrasonic vibrations



Refill friction stir process



frictional heat



Conclusions

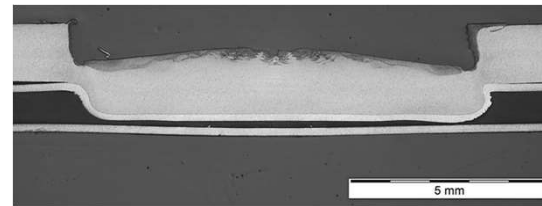
Joining of conventional aluminium sheets to MPC sheets with displaced core :

Refill friction stir spot welding

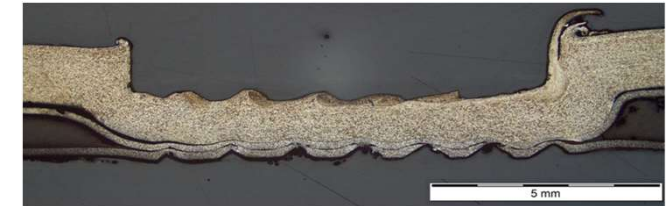


Joining of conventional aluminium sheets to MPC sheets with non-displaced core :

Friction stir spot welding



Ultrasonic welding



Refill friction stir spot welding



Refill friction stir spot welding (double config.)



General conclusion

- ▶ Good weld quality
- ▶ Further optimisation possible :
 - ▶ Minimise deformation of the sheets
 - ▶ Removal of coating ?
 - ▶ Minimise influence of heat (decolourisation)
 - ▶ Esthetical aspects