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Mechanical Behaviour of Friction Stir Overlap Welds for Aeronautical Applications

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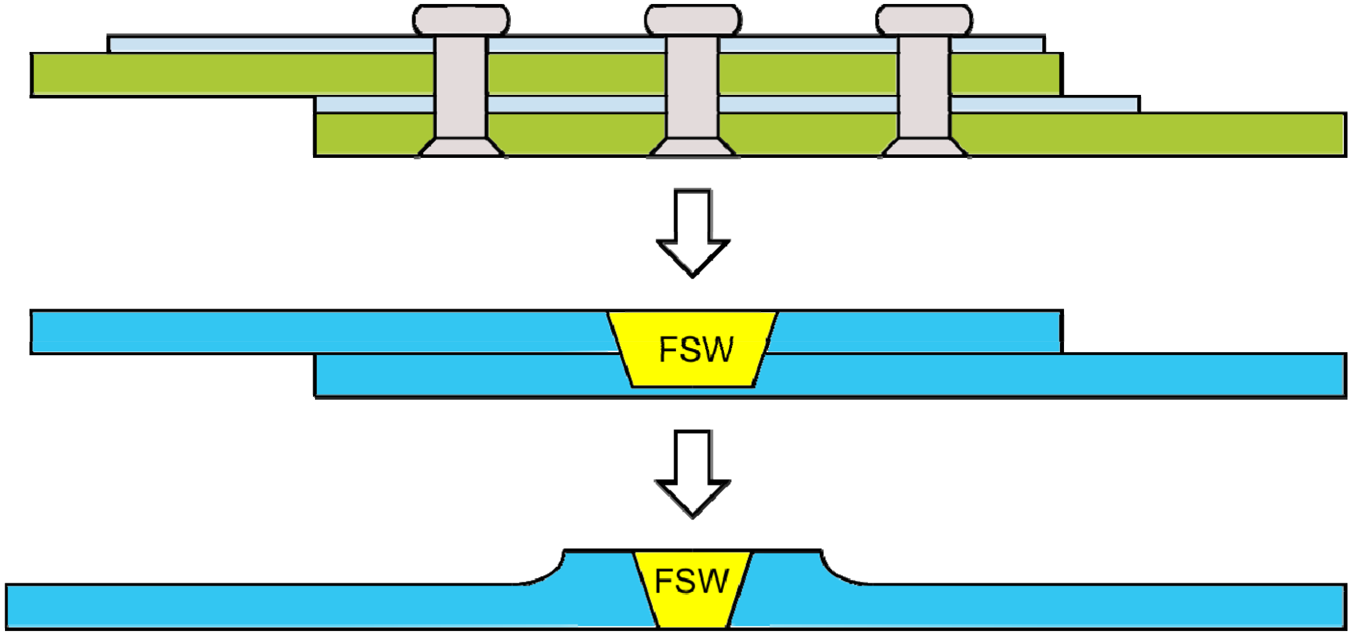
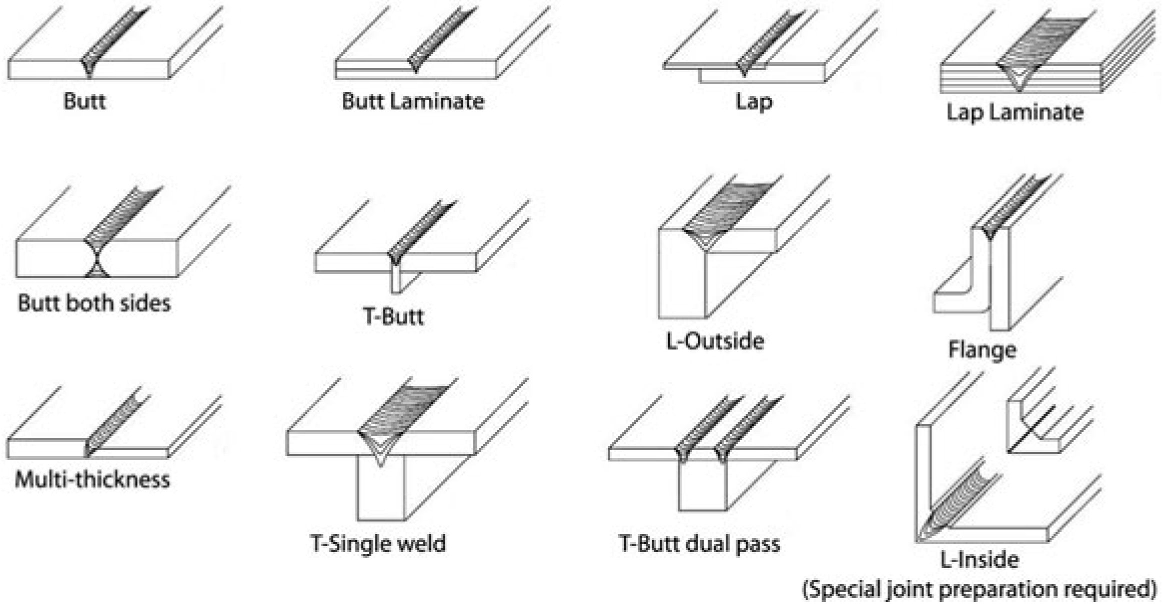
Introduction

- New joining processes associated with new materials can improve the aeronautical structures, reducing their environmental impact and improving their efficiency.
- FSW can replace older joining processes in these structures, mainly riveting, creating leaner joints at lower costs.



FSW Joints



Source: http://www.mtiwelding.com/equipment/2/Friction-Stir-Joint-Geometries

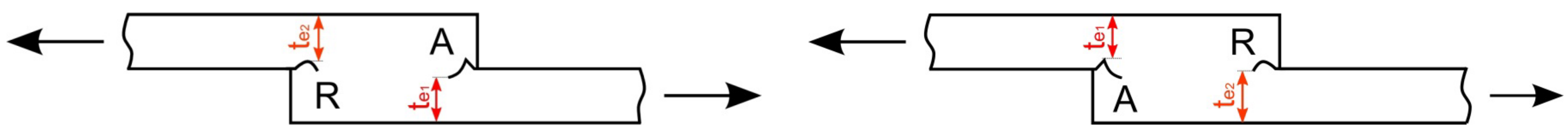
- Butt-joints are “leaner” joint geometries when compared with other joint types. However, achieving the tight tolerances required for FSW butt-joints in large structures is a big assembly challenge; this can limit the application of this configuration, preventing its application for major component assembly and final assembly
- Overlap joints allow a smoother transition to join large structures due to the easier tolerance management and reaction to the forging loads during the process

FSW overlap joints (1)

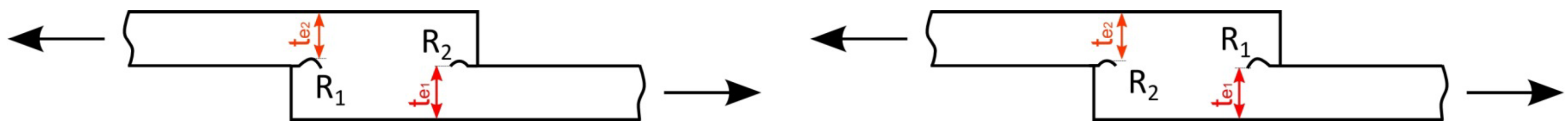
Due to the vertical material flow, the sheets interface pulls up and down creating a interface of unwelded material. In the advancing side, this interface effect takes the shape of a hook (due the pull up and pull down effect) and in the retreating side, a pull up effect takes place. The shape of these defects are function of the process parameters and tool geometry. These defects cause a reduction of the real cross section and an increase of the stress concentration factor at the interface tips

Cederqvist and Reynolds, 2001, identified the next interface defects shapes

- Single pass:



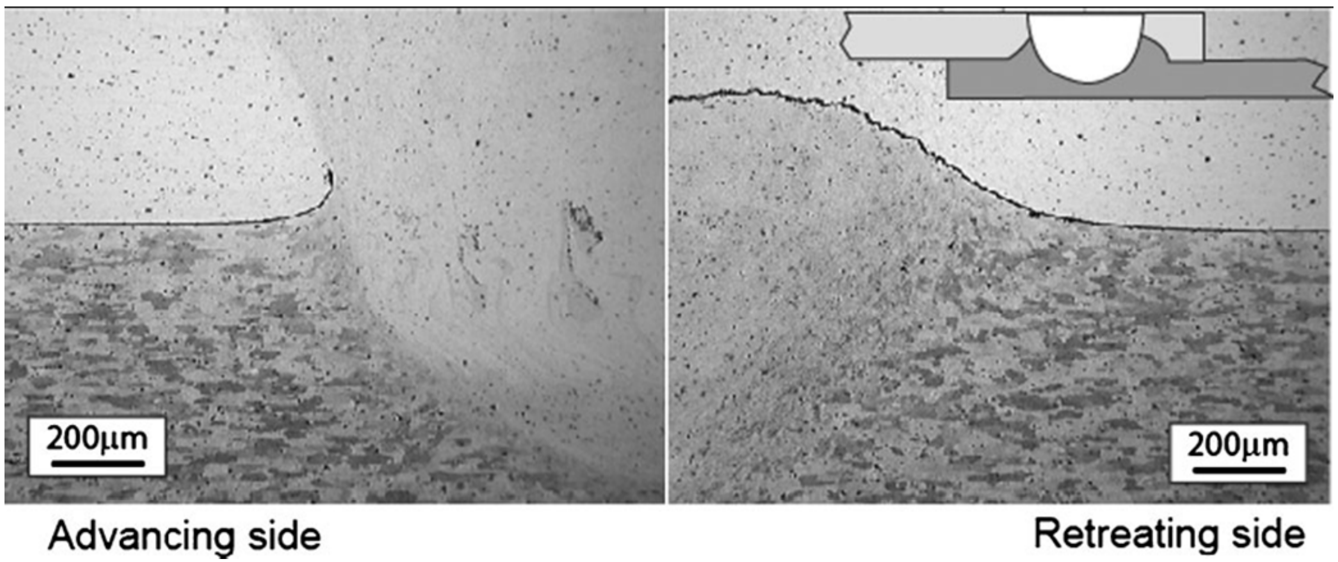
- Double pass:



FSW overlap joints (2)

With low heat input and a different tool, the hook shape can be slightly different, as found by Yazdanian and Chen (2009)

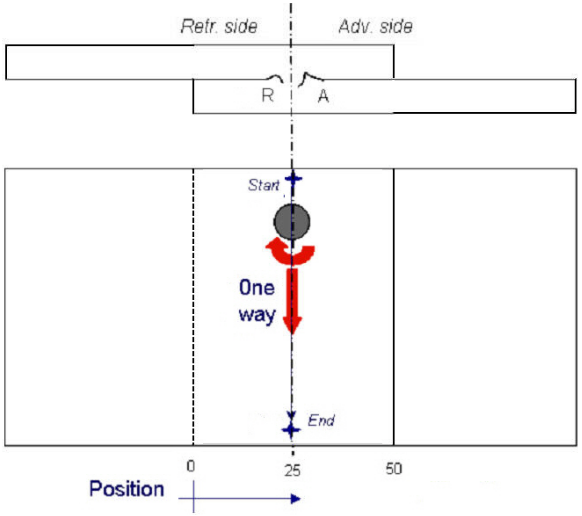
and Threadgill *et. al.* (2009) for a overlap AA2024-T3 with AA7075-T6:



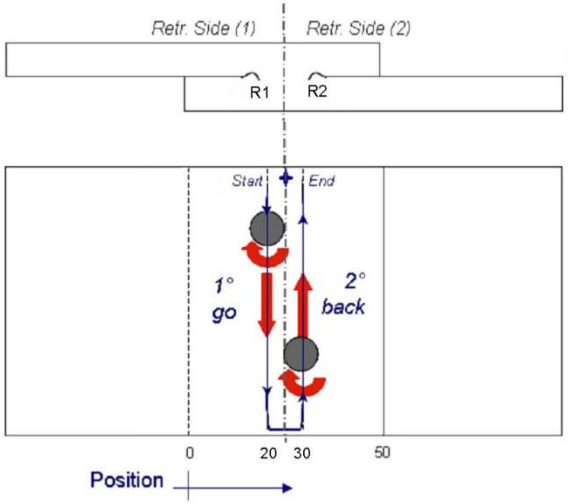
Experimental plan (1)

Multiple overlap configurations were tested in order to assess the joint performance under fatigue loads.

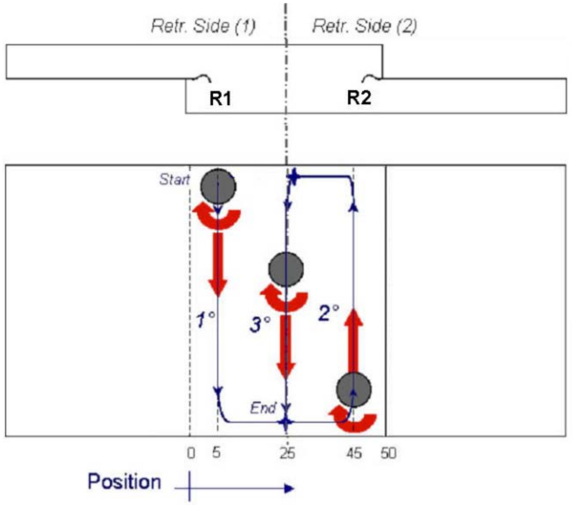
The welds were performed by EADS IW Ottobrunn and the tests done at University of Patras.



Single pass



Double pass



Triple pass

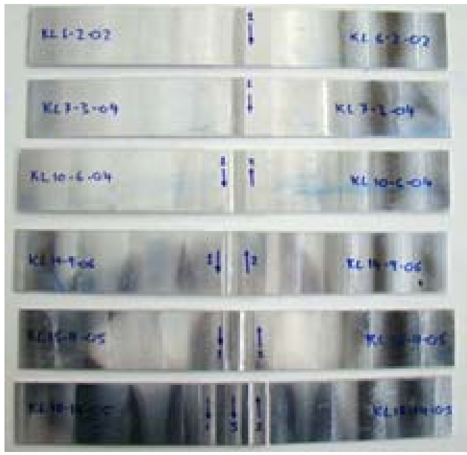
Experimental plan (2)

Weld Type	Label	Pin length [mm]	No. of passages	Position(s) [mm]
A	KL6-2	3.0	1	25
A	KL7-3	3.0	1	25
B	KL10-6	3.0	2	25-25
C	KL14-9	3.0	2	23-27
D	KL15-11	3.0	2	20-30
E	KL18-14	3.0	3	5-25-45

AA2024-T3 alclad sheets

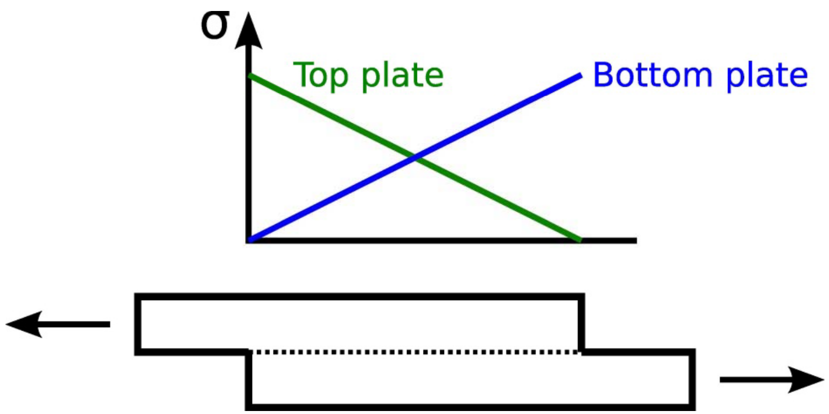
Welding parameters:

- Vertical force: 8kN
- Welding speed: 140 mm/min
- Rotational speed: 500 rpm (clockwise)



Stress analysis of overlap joint (1)

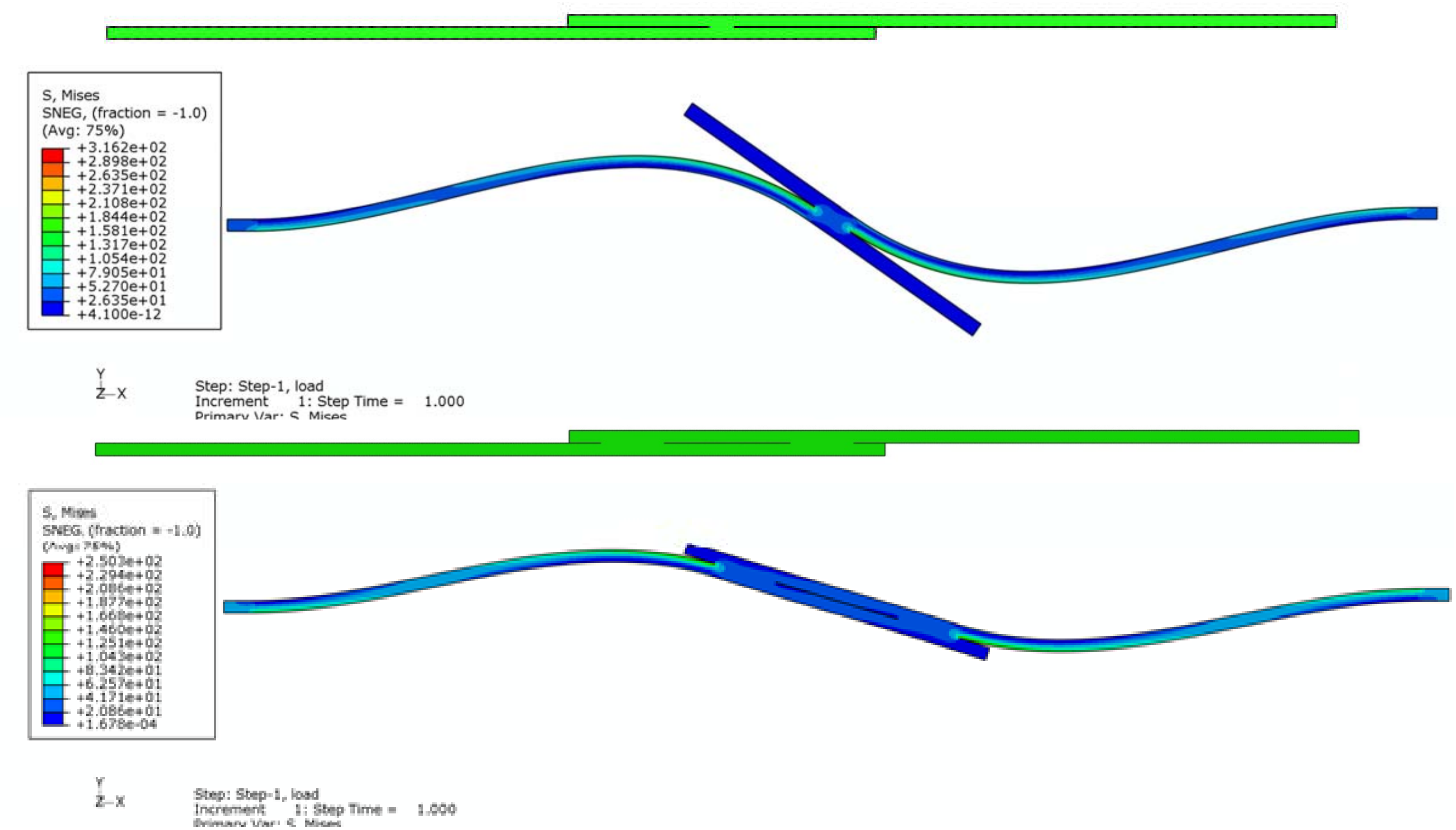
A theoretically distribution of the joint stresses in an overlap joints, without taking into account the boundary effects:



However, the stress concentrations in the limits of the joint weakens this type of joint

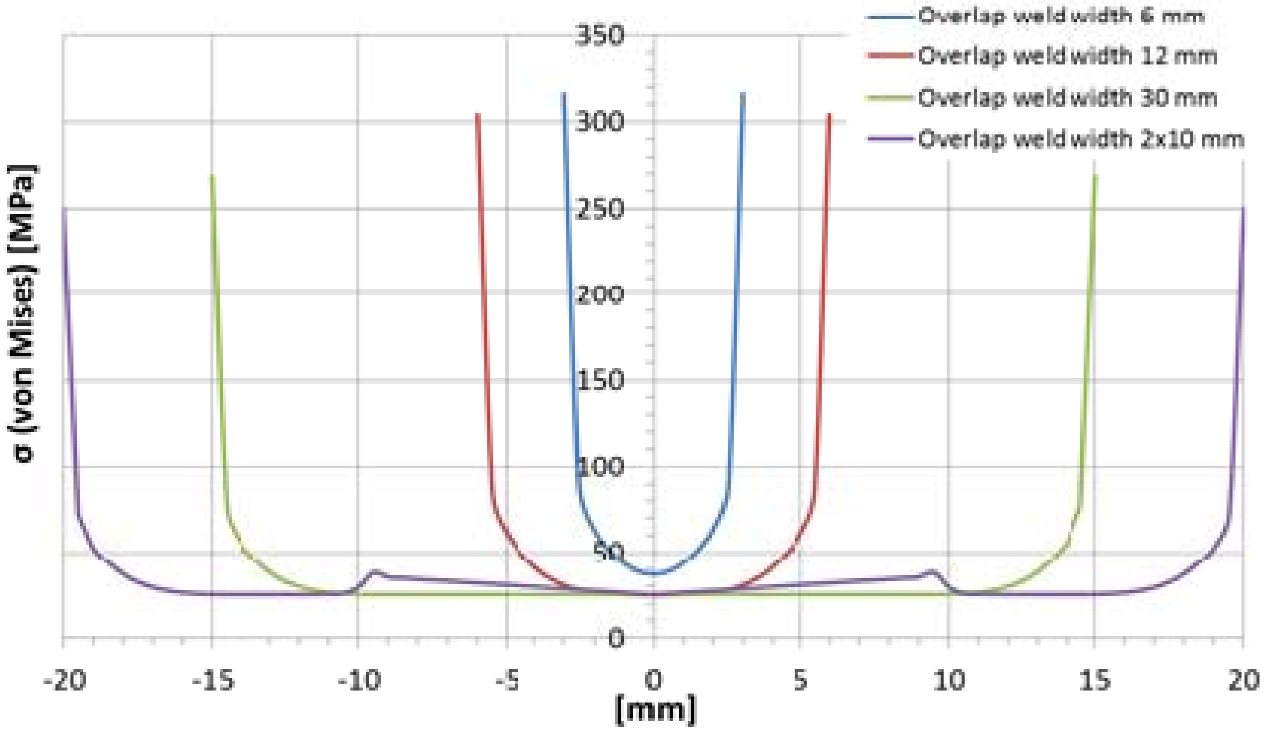
Stress analysis of overlap joint (2)

For 6 mm and 2x10 mm welded length (50 MPa remote load: von Mises stresses and deformation magnified 15x):



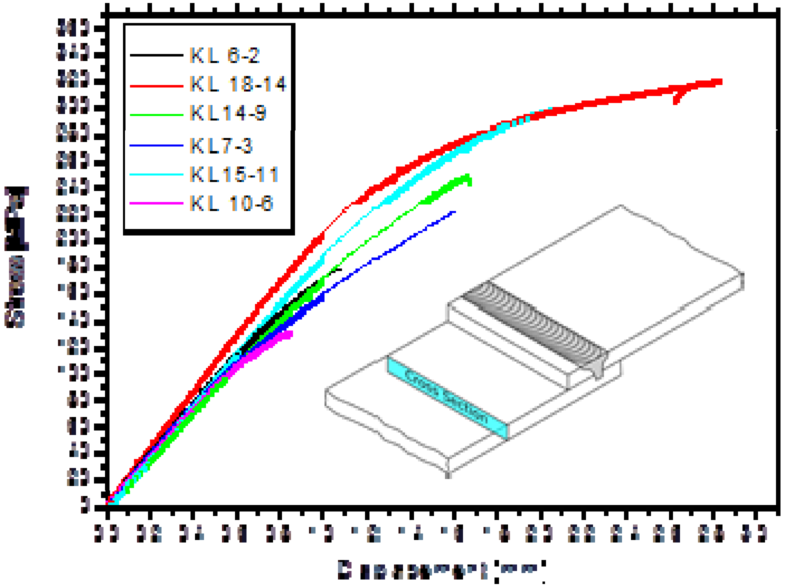
Stress analysis of overlap joint (3)

von Mises stress evolution along the joined width:



The increase of the weld width decreases the stresses concentration, although this reduction is slight

Results – Static Strength

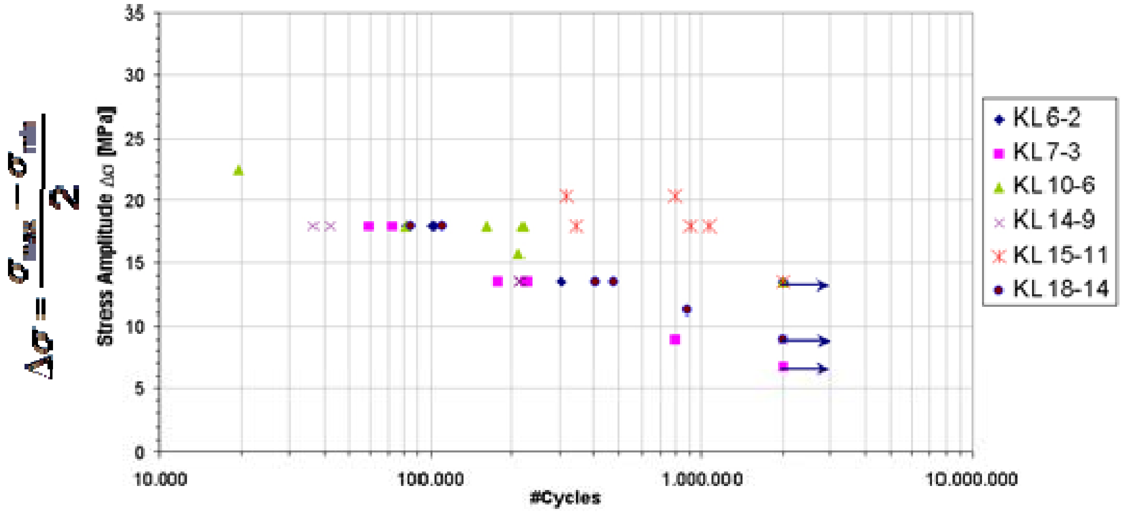


Weld Type	Weld Label	Tensile strength [MPa]	Efficiency
A	KL6-2	188.5	44.4%
A	KL7-3	226.4	53.3%
B	KL10-6	149.5	35.2%
C	KL14-9	256.8	60.4%
D	KL15-11	303.5	71.4%
E	KL18-14	300.5	70.7%

$$Efficiency = \frac{\sigma_{max\ cross\ section}}{\sigma_{UTS}} [\%]$$

As expected, the multi pass welds present higher efficiency and the increase of distance between passages is beneficial

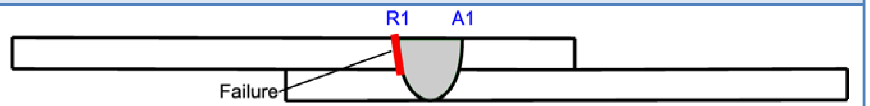
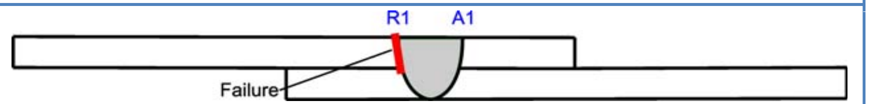
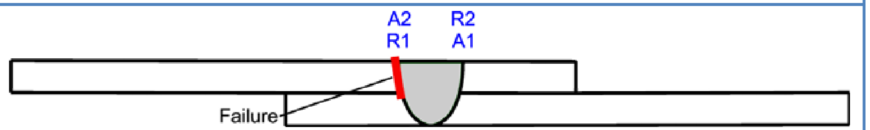
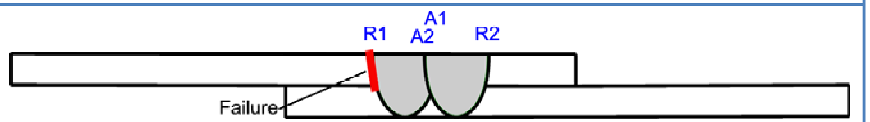
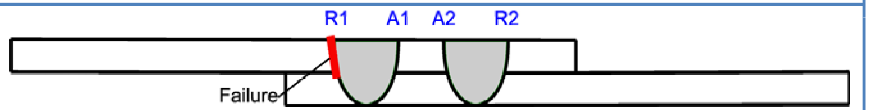
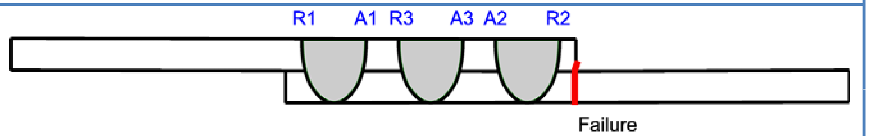
Results – Fatigue Strength (1)



Weld Type	Weld configuration	Δσ [MPa]	
		1E+05 Cycles	1E+06 Cycles
A	KL6-2, Single Pass A*	17,4	14,0
A	KL7-3, Single Pass B*	16,1	8,4
B	KL10-6, Double Pass: 25-25	19,0	14,1
C	KL14-9, Double Pass: 23-27	15,3	10,2
D	KL15-11, Double Pass: 20-30	24,2	17,1
E	KL18-14, Triple Pass: 5-25-45	18,1	10,9

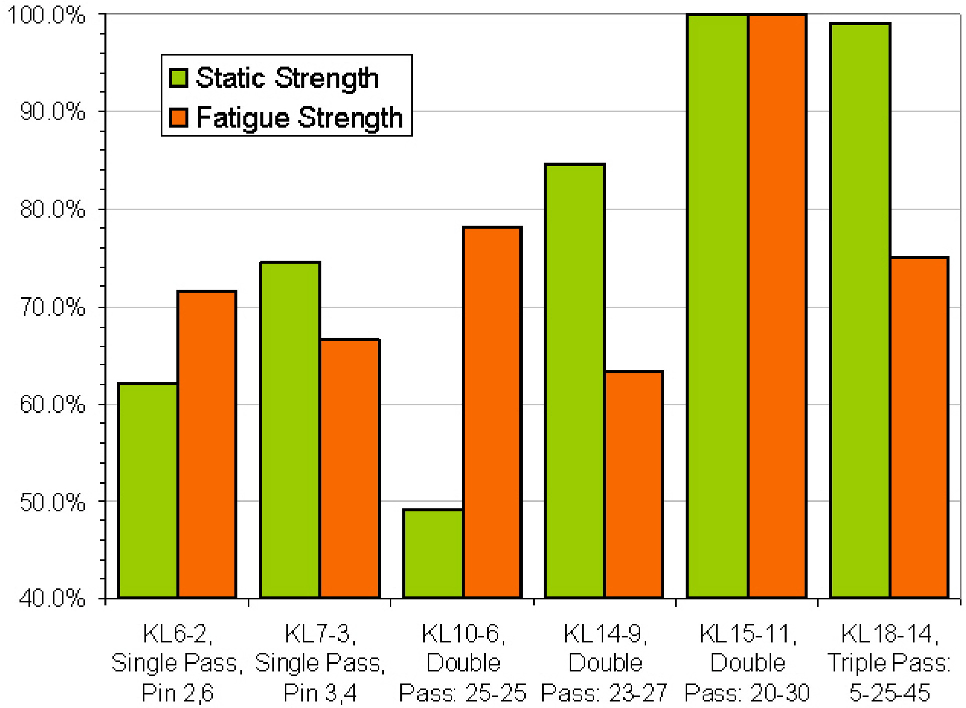
Results – Fatigue Strength (2)

Failure location in the fatigue tests. The failure was always in the first retreating side due to the hook defect tip orientation

Weld Type	Weld Configuration	Fatigue Failure Location
A	KL6-2	
A	KL7-3	
B	KL10-6	
C	KL14-9	
D	KL15-11	
E	KL18-14	

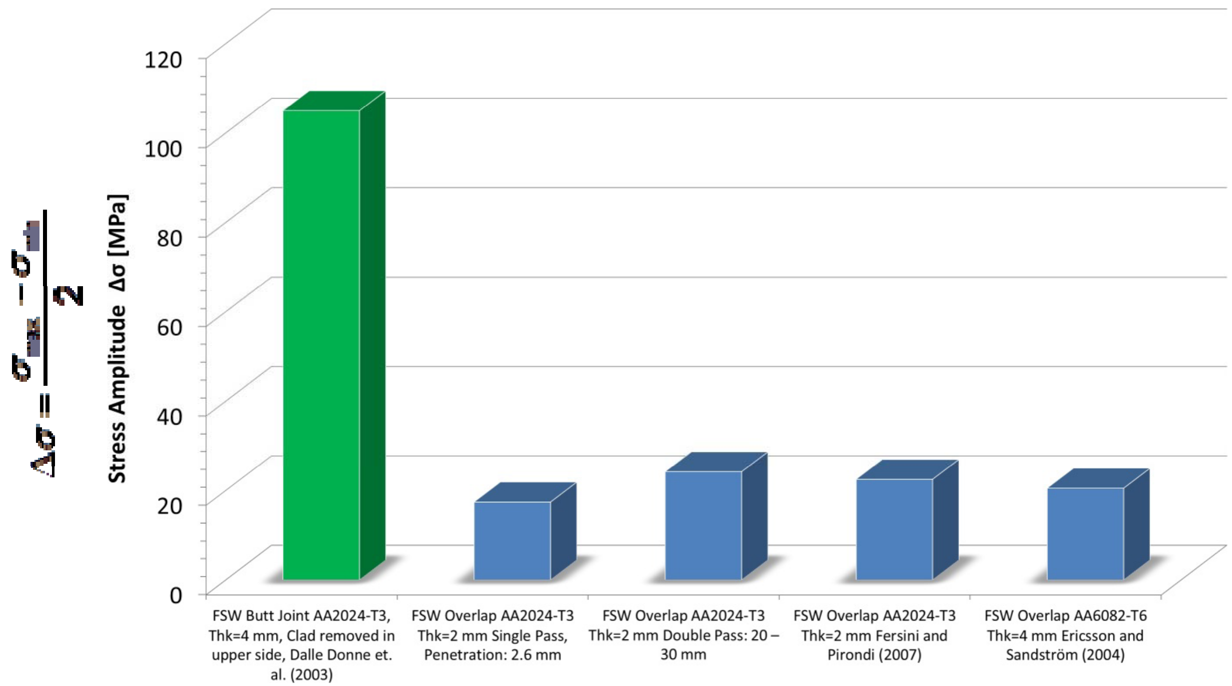
Results Assessment (1)

Comparing the static strength and fatigue strength values with the higher achieved values, it is concluded that the higher static strength does not corresponds to the higher fatigue strength



Results Assessment (2)

Evaluating the fatigue strength of the overlap results with literature results and with butt-joints results it is concluded that the overlap joints fatigue strength is about 6x lower than an equivalent overlap joint.



Conclusions

- FSW overlap joints have the advantage of the similar tolerance management as the riveting process, making its application for assembly of aircraft primary structures very attractive
- The vertical material flow during the FSW process pulls up the interface between the two plates, decreasing the effective strength area and creating notches. These notches at the interface of the surfaces typically have a shape of a hook and they are unavoidable and deteriorating the joint performances, in particular the fatigue strength
- Multi passages can improve the joint strength, although just a slight enhancement is expected
- The fatigue performance of full load transfer FSW overlap joints is poor in comparison to a FSW butt joint and the application for a primary joint with high fatigue requirement is not recommended

Thank you for your attention!