

JOIN'EM

INDUSTRIAL TECHNOLOGIES FOR ADVANCED JOINING AND
ASSEMBLY PROCESSES FOR MULTI-MATERIALS

Process analysis for magnetic pulse welding of copper tubes to stainless steel rods

I²FG workshop on impulse metalworking 2017

November 29th, 2017

Berlin, Germany



Parameters for tube welding

Parameters for detailed investigation

Capacitor charging energy E

Tube wall thickness $w.t.$

Initial gap between flyer and target g_{initial}

Overlap O

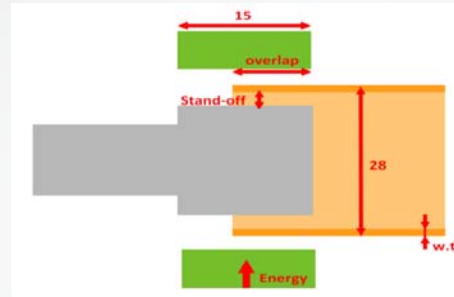
Pulsar 9 kV – 25 kJ

Fixed parameters

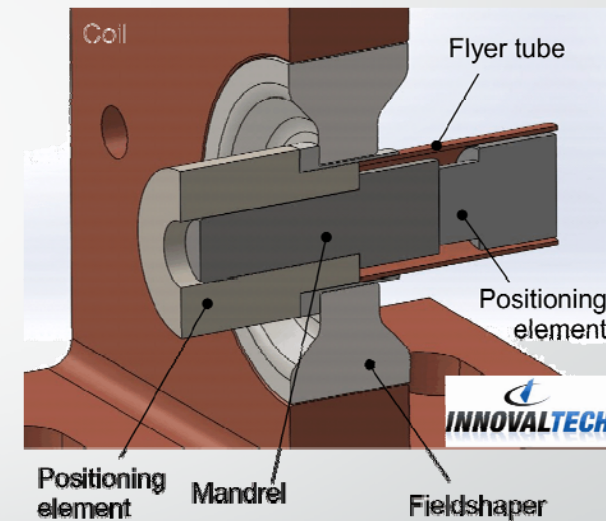
Capacitance C (690 μF)

Outer diameter of the flyer tube D_o (28 mm)

Active length of the coil or field shaper l (15 mm)

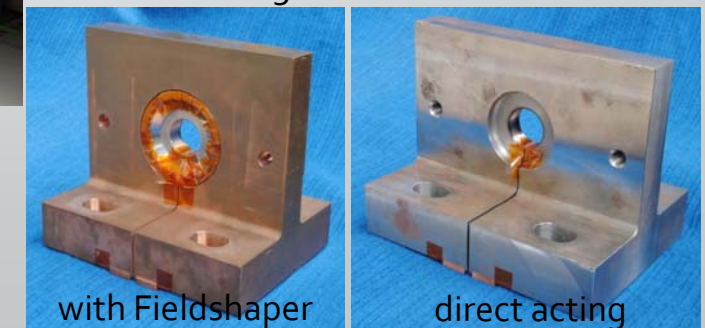


Experimental setup



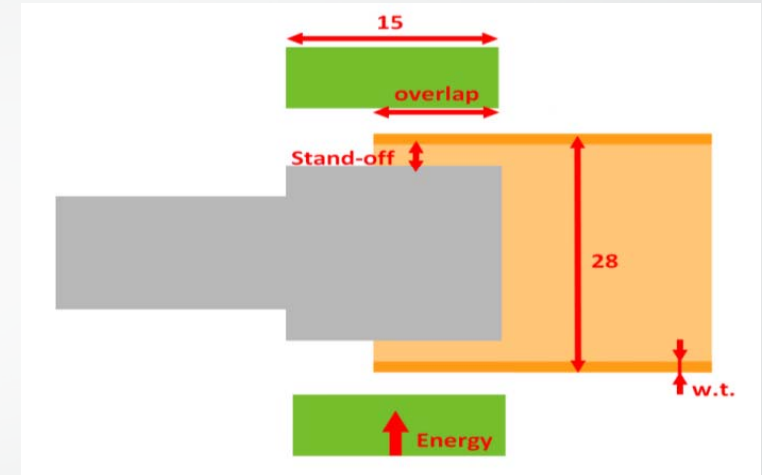
Compression coils

Single-turn coils



Copper tube to stainless steel rod: parameter values

- Flyer: Cu-DHP R250 tube
 - ✓ O.D.: 28 x 0.9 mm
 - ✓ O.D.: 28 x 1.3 mm
- Target: stainless steel 304L (1.4307)
solid internal workpiece (rod)



Field shaper designed for O.D. 28 mm



Test series	Configuration	Coil system	Wall thickness (mm)	Voltage (kV)	Energy (kJ)	Gap (mm)	Overlap (mm)	# exp.
R1	Tube-to-rod without a shoulder	Single-turn & field shaper	0.9 & 1.3	7.4-8.5	19-25	1-2-3	6-8-10	36
R2		Single-turn without field shaper	0.9 & 1.3	7.1-8.5	17.5-20-22.5-25	1-2-3	6-8-10	54

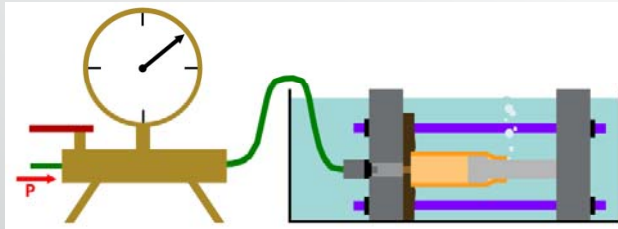
Coil designed for O.D. 28.5 mm

Results: Joint quality parameters

Results for welding CU-DHP R250 tubes (OD 28 x 0.9 mm and 28 x 1.3 mm) to 1.4307 rods

	Frequency	Maximum current
With field shaper	20 to 21 kHz	510 kA (19 kJ) 580 kA (25 kJ)
With direct acting coil	22 to 23 kHz	533 kA (17.5 kJ) 570 kA (20 kJ) 605 kA (22.5 kJ) 640 kA (25 kJ)

Leak test with air



No leak free assembly obtained with the field shaper.

Many leak free assemblies obtained with the direct acting coil.

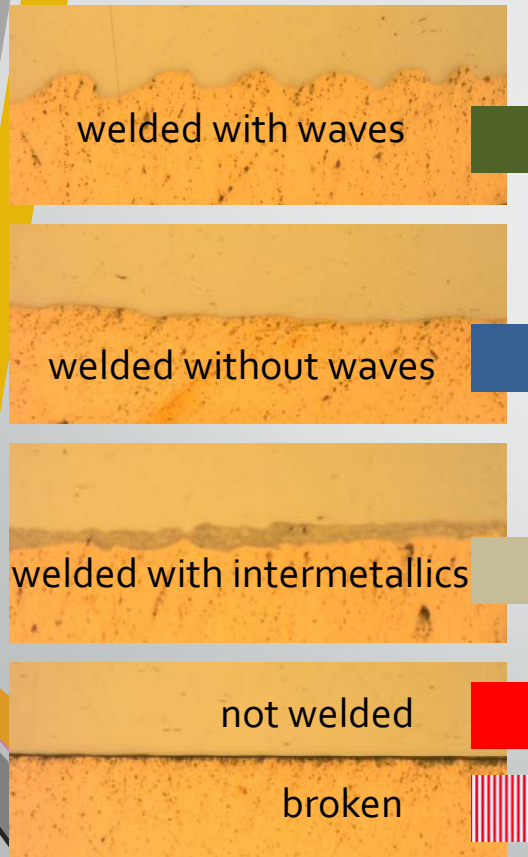


Weld characterisation: Copper tube to stainless steel rod

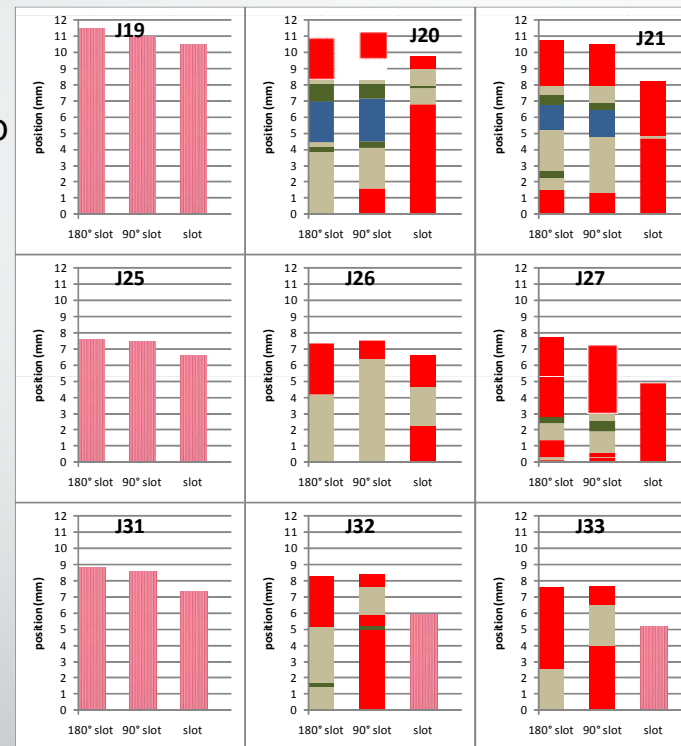
Metallography

- Coil system: Single-turn coil with field shaper
- Energy: 25 kJ

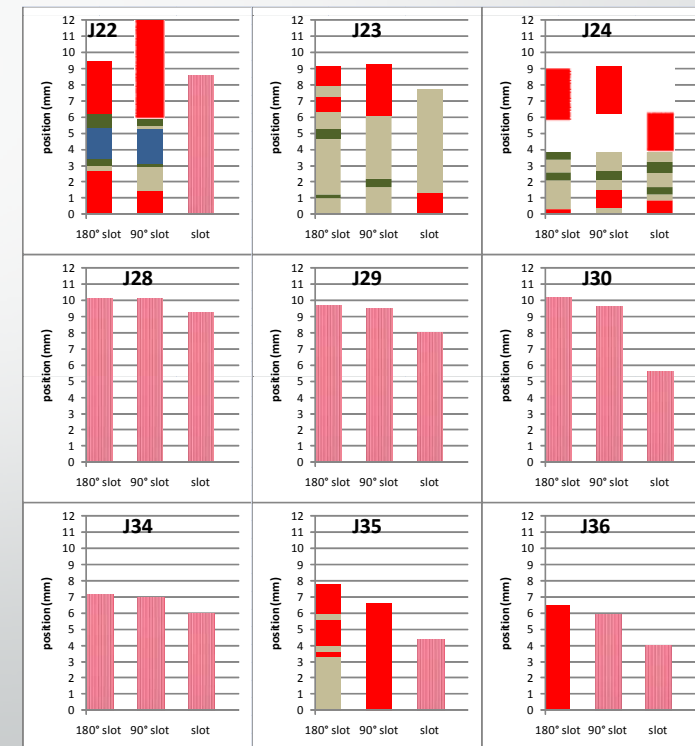
different types of interfaces



Tubes with a wall thickness: 0.9 mm



Tubes with a wall thickness: 1.3 mm



10

8

6

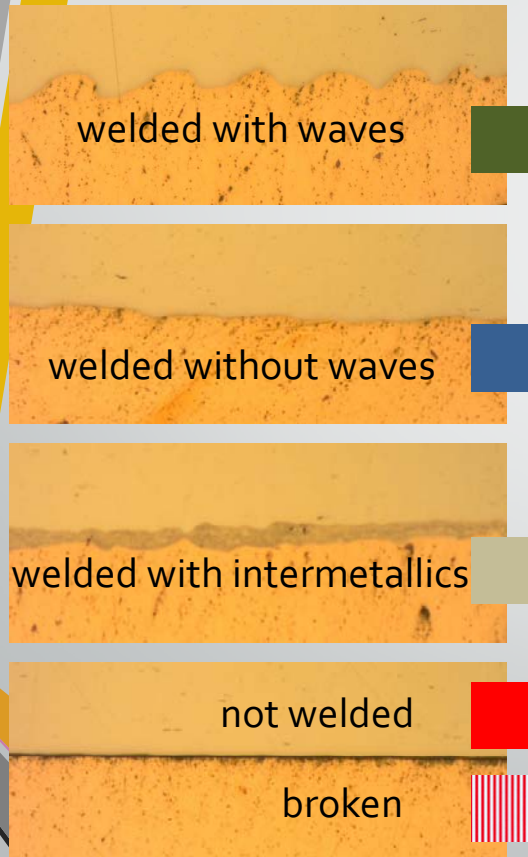
overlap in mm

Weld characterisation: Copper tube to stainless steel rod

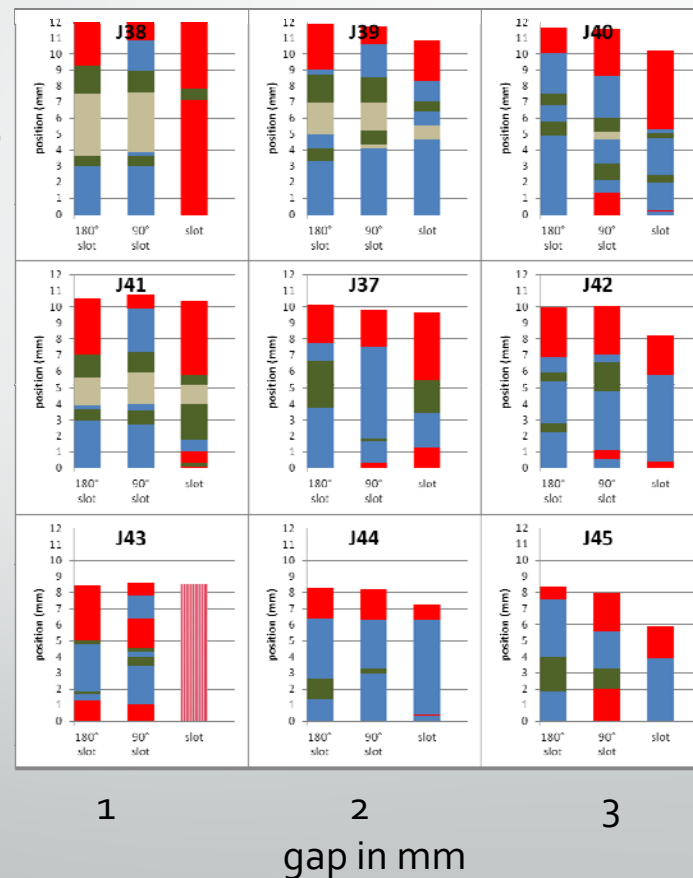
Metallography

- Coil system: Single-turn coil without field shaper
- Energy: 25 kJ

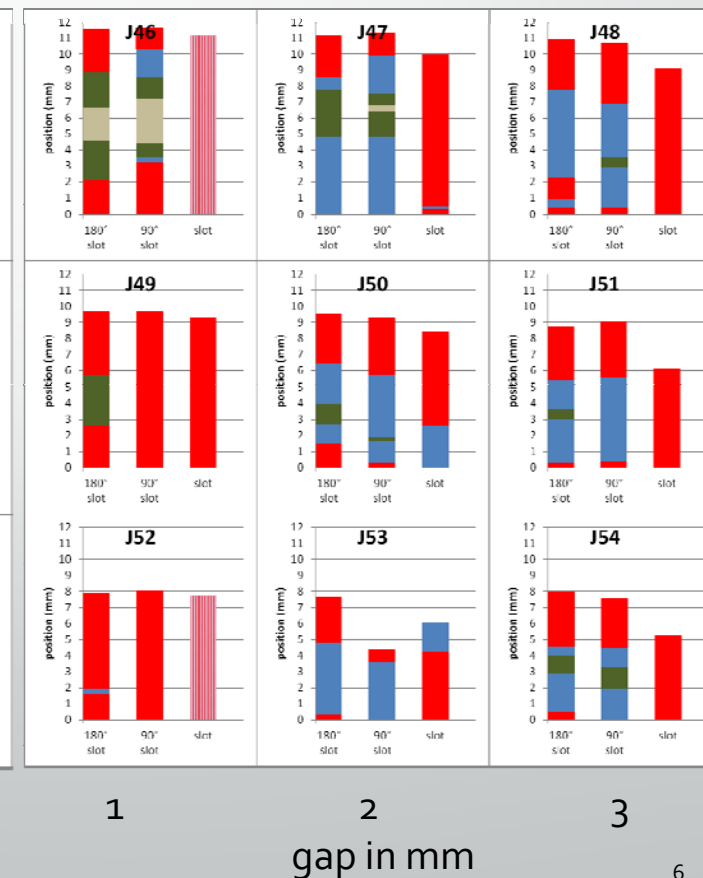
different types of interfaces



Tubes with a wall thickness: 0.9 mm



Tubes with a wall thickness: 1.3 mm



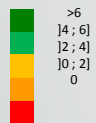
Welding window: Copper tube to stainless steel rod

- Flyer: Cu-DHP R250: tube with wall thickness: 0.9 & 1.3 mm
- Target: stainless steel 304L (1.4307): solid internal workpiece (rod)

- Coil system: Single-turn coil with field shaper
- Freq. & current for welding: 20.7 kHz & 580 kA (field shaper)

Tubes with a wall thickness: 0.9 mm

Weld length (mm)

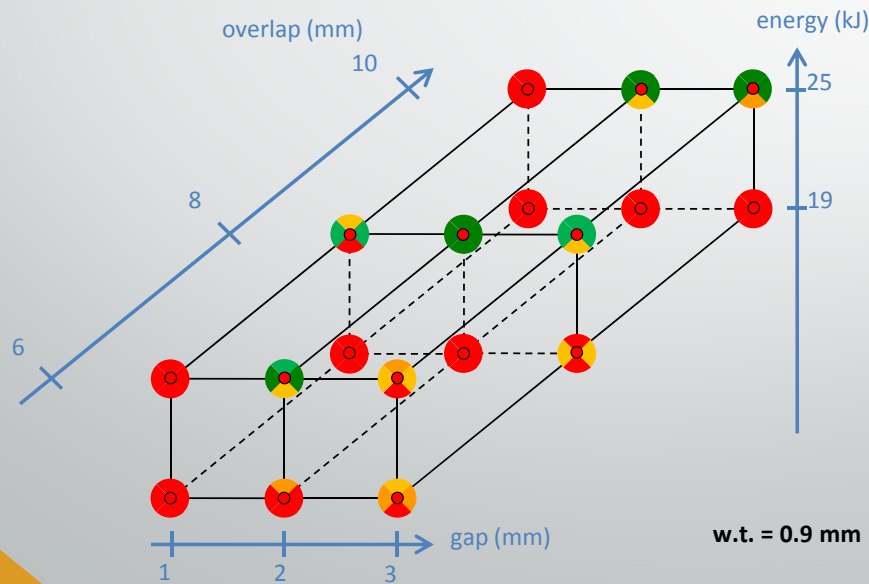


180° of the field shaper cut

90° of the field shaper cut

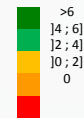
Leak free (green) or leak (red)

In front of the field shaper cut



Tubes with a wall thickness: 1.3 mm

Weld length (mm)

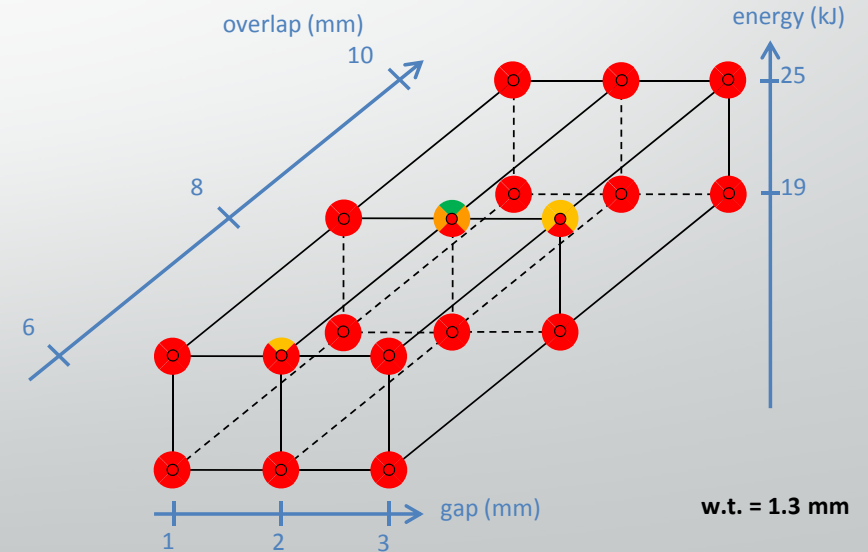


180° of the field shaper cut

90° of the field shaper cut

Leak free (green) or leak (red)

In front of the field shaper cut



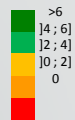
Welding window: Copper tube to stainless steel rod

- Flyer: Cu-DHP R250: tube with wall thickness: 0.9 & 1.3 mm
- Target: stainless steel 304L (1.4307): solid internal workpiece (rod)

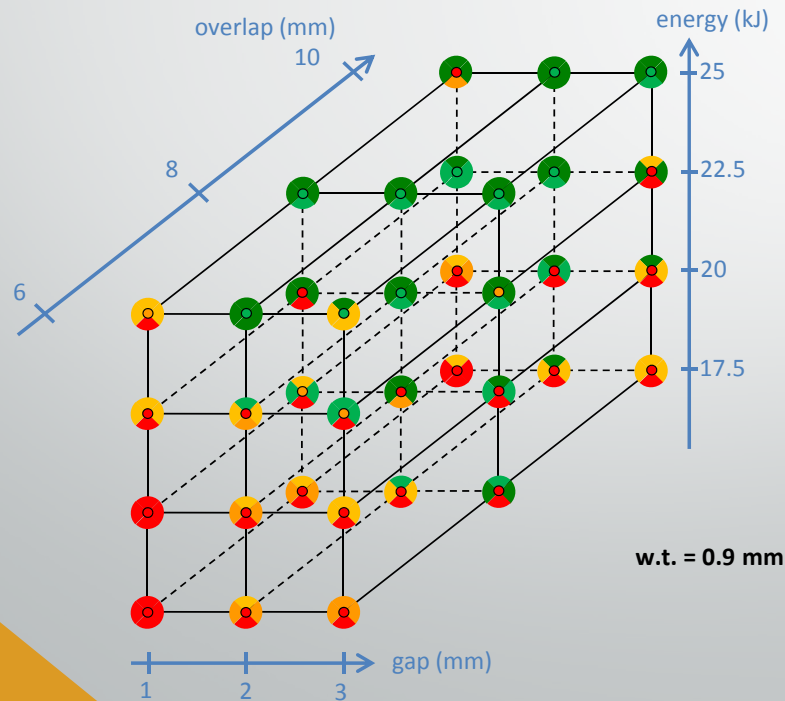
- Coil system: Single-turn coil without field shaper
- Freq. & current for welding: 22.5 kHz & 605 kA

Tubes with a wall thickness: 0.9 mm

Weld length (mm)



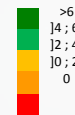
180° of the field shaper cut
 90° of the field shaper cut
 Leak free (green) or leak (red)
 In front of the field shaper cut



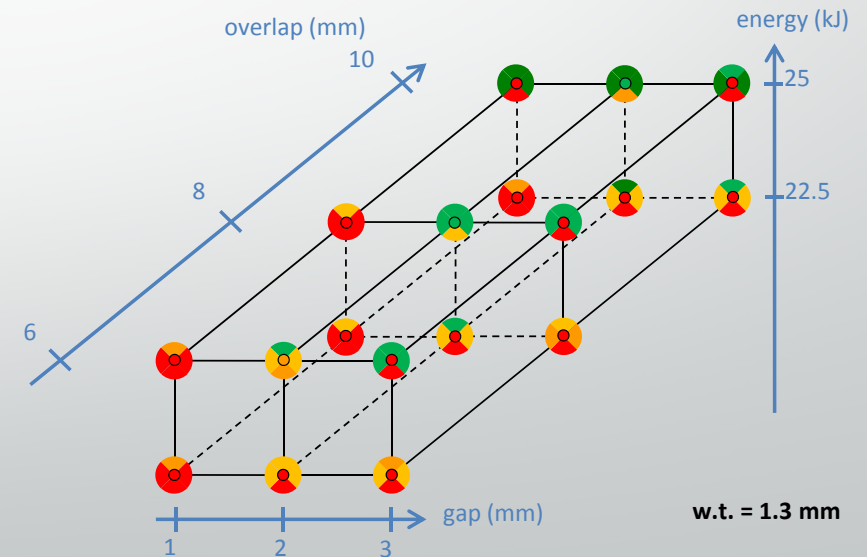
w.t. = 0.9 mm

Tubes with a wall thickness: 1.3 mm

Weld length (mm)



180° of the field shaper cut
 90° of the field shaper cut
 Leak free (green) or leak (red)
 In front of the field shaper cut



w.t. = 1.3 mm

Correlation of joint preparation (roughness) and weld morphology by EMW (tube)

welded with waves



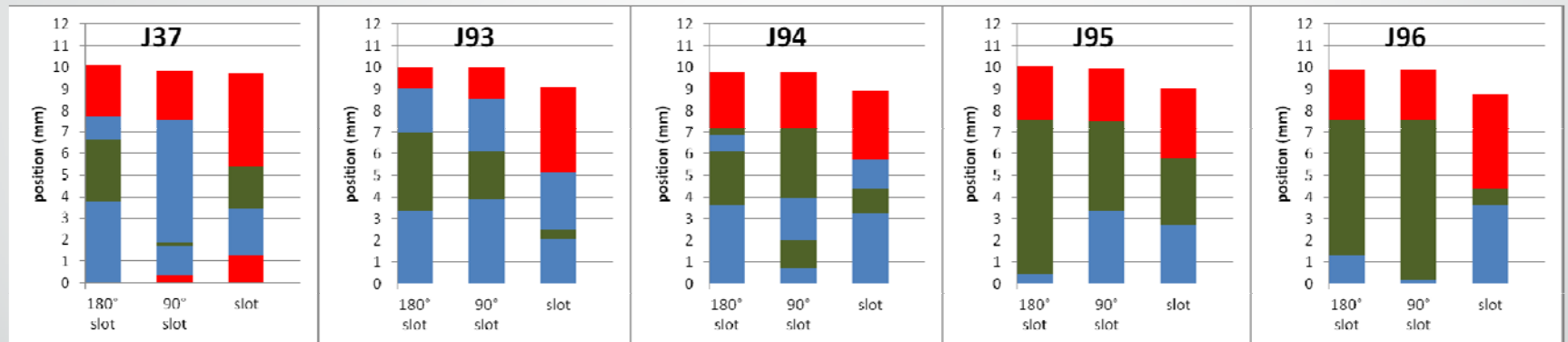
welded without waves



welded with intermetallics



not welded



Roughness → Ra 0.81 μm (standard)

Ra 1.49 μm

Ra 3.20 μm

Ra 5.53 μm

Ra 9.89 μm

Fixed process parameters for this test series

Flyer tube: Cu-DHP; 0.9 mm thick

Target: stainless steel 304L (1.4307); rod

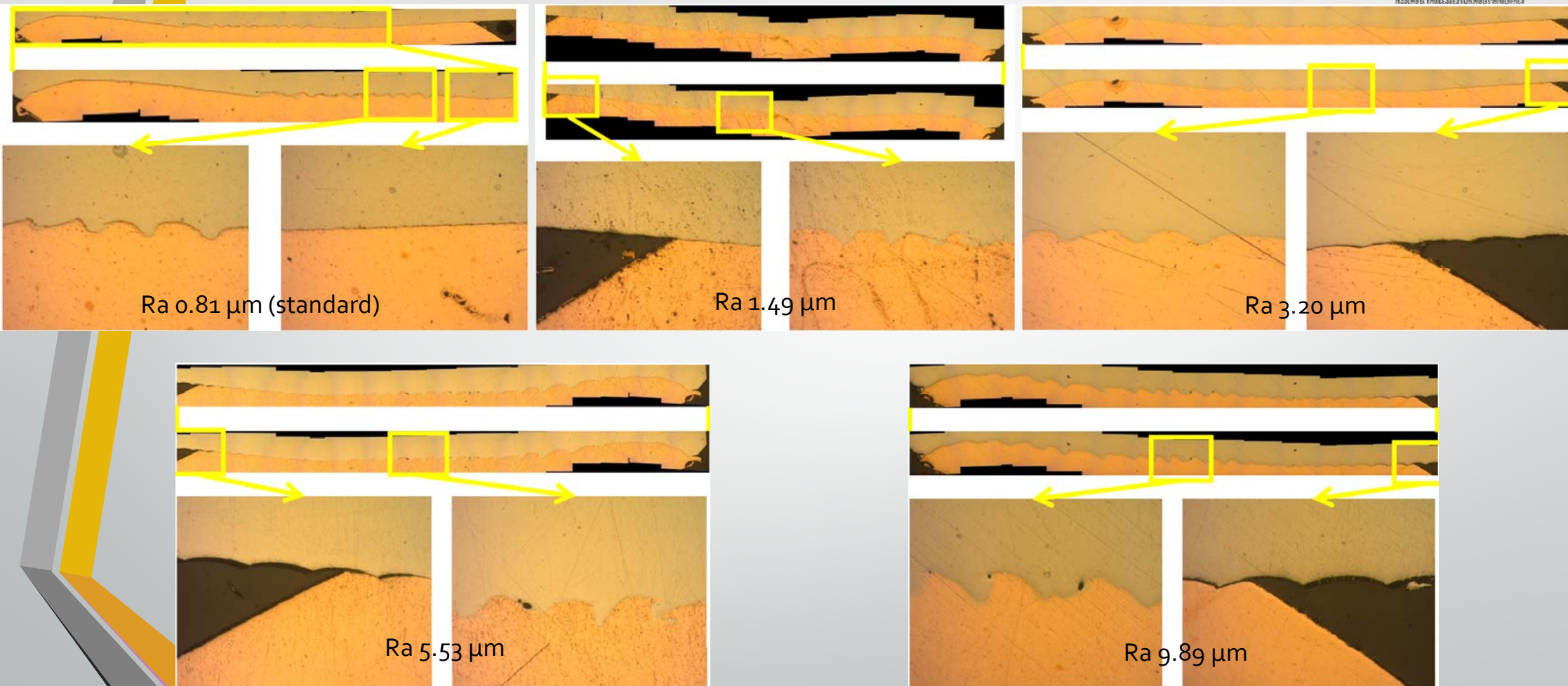
Initial gap: 2 mm

Overlap: 8 mm

The increased roughness:

- contributes to the weld initiation
- increases the weld length containing waves

Micrographs at 180° from de coil slot f(roughness)



➤ The roughness of the target part helps to initiate de wavy shape of the welded interface.

Summary

- The process parameters have been tested in 5-D:
 - Single-turn coil with/without field shaper
 - Capacitor charging energy
 - Tube wall thickness
 - Initial gap between flyer and target
 - Overlap
- The direct acting single-turn coil is more effective than the single-turn coil with field shaper to obtain leak free assemblies.
- The results are presented with a 3D overview, helpful to determine the optimal welding parameters.
- The effect of the roughness of the target part has been tested.
 - The roughness of the target part helps to initiate the wavy shape of the welded interface.

- Questions?
- Comments?

THANK YOU

Acknowledgement

- The JOIN'EM project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 677660.

