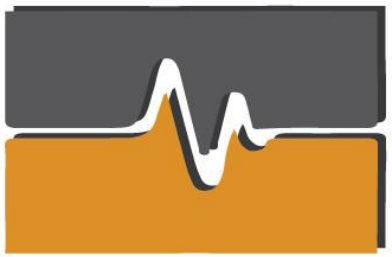

JOIN'EM

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

Laser Ultrasound as a tool for the characterisation of electromagnetic welded joints

Christian Hofer[1], Klarissa Meirer[1], Verena Psyk[2], Koen Faes[3], Edgar Scherleitner[1], Bernhard Reitinger[1]

1-Research Center for Non-Destructive Testing GmbH (RECENDT), 2-Fraunhofer Institute for Machine Tools and Forming Technology (IWU), 3- Belgian Welding Institute (BWI)

6th International Symposium on Laser Ultrasonics - LU2018

July 10th, 2018, Nottingham

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Agenda

- Motivation
- Process principle: Magnetic Pulse Welding (MPW)
- LUS on MP welded sheet metal specimen
  - Setup
  - Results
- LUS on MP welded tubular specimen
  - Setup
  - Results
- Summary and conclusions

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Motivation

- Increasing awareness of responsibilty for environmental protection and ressource efficiency
- Increasing significance of product weight
- Multi-material design allows
  - Weight savings
  - Improved product performance
  - Cost reduction
- Increasing need of innovative joining technologies allowing the production of high quality joints for complex material combinations such as e.g.
  - Copper / aluminium
  - Steel / aluminium

Agenda 2030

- New inspection methods for new joining technologies

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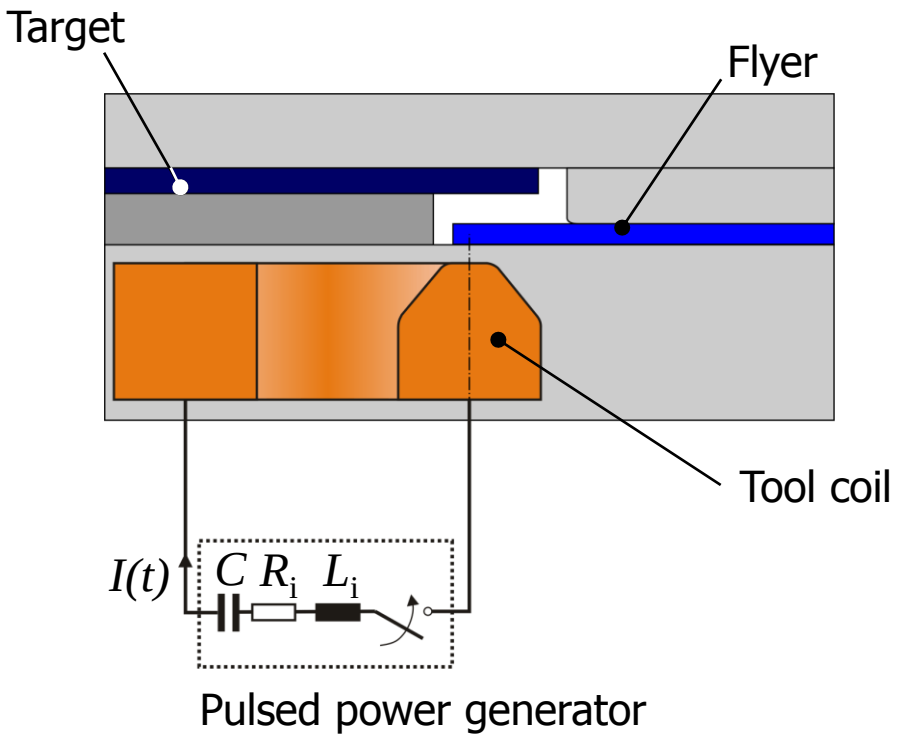
Magnetic pulse welding - process principle

Exemplary setup of a sheet welding process



Characteristics of MPW

- Joint produced by high speed collision of flyer and target
- No significant heating of the parts
- No temperature induced problems (intermetallics, thermal softening, etc.)
- Conventionally non-weldable material combinations possible (e.g. Cu - Al, (stainless) steel - Al)
- High quality joints:
  - Mechanical strength
  - Electrical conductivity
- Applicable for tube and sheet metal

V. Psyk et al., Manufacturing of Hybrid Aluminum Copper Joints by Electromagnetic Pulse Welding, ESAFORM 2017

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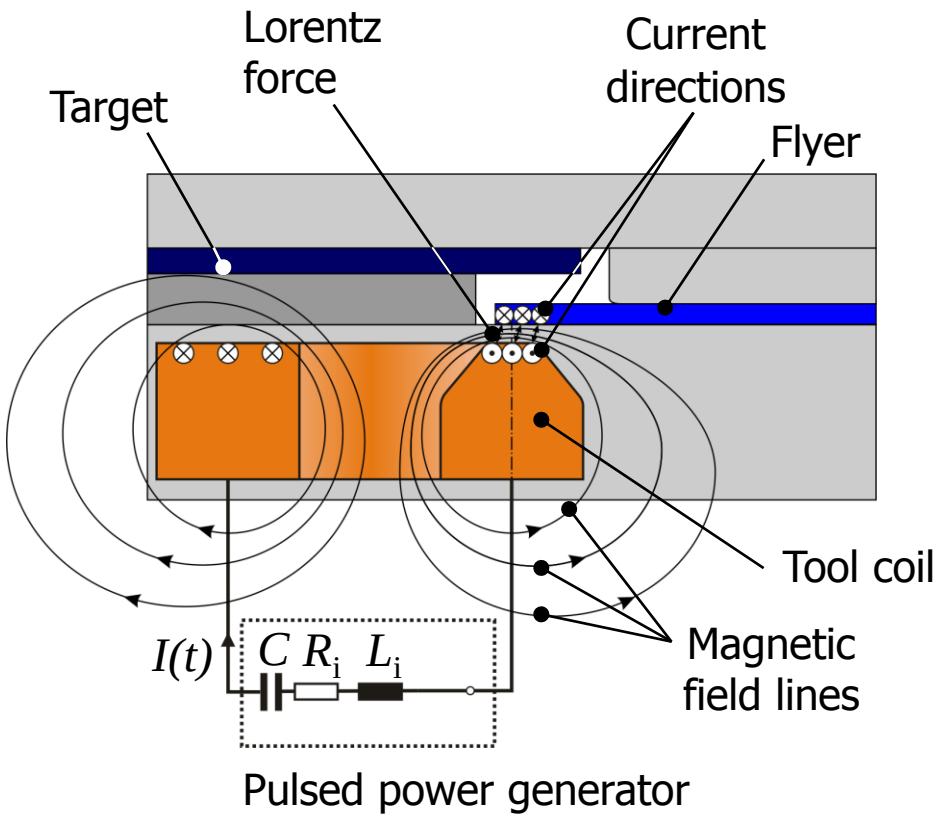
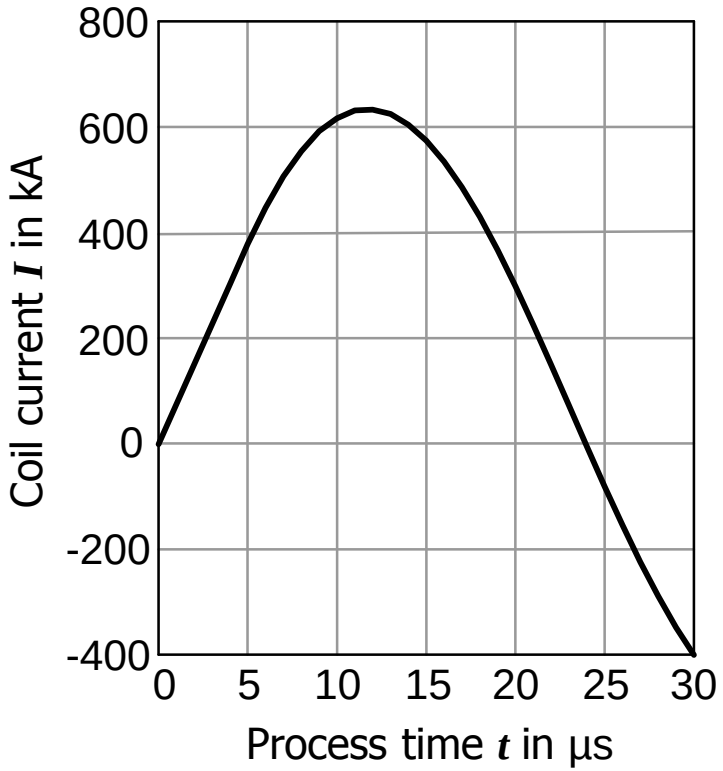
Magnetic pulse welding - process principle

Exemplary setup of a sheet welding process



Course of the coil current



V. Psyk et al., Manufacturing of Hybrid Aluminum Copper Joints by Electromagnetic Pulse Welding, ESAFORM 2017

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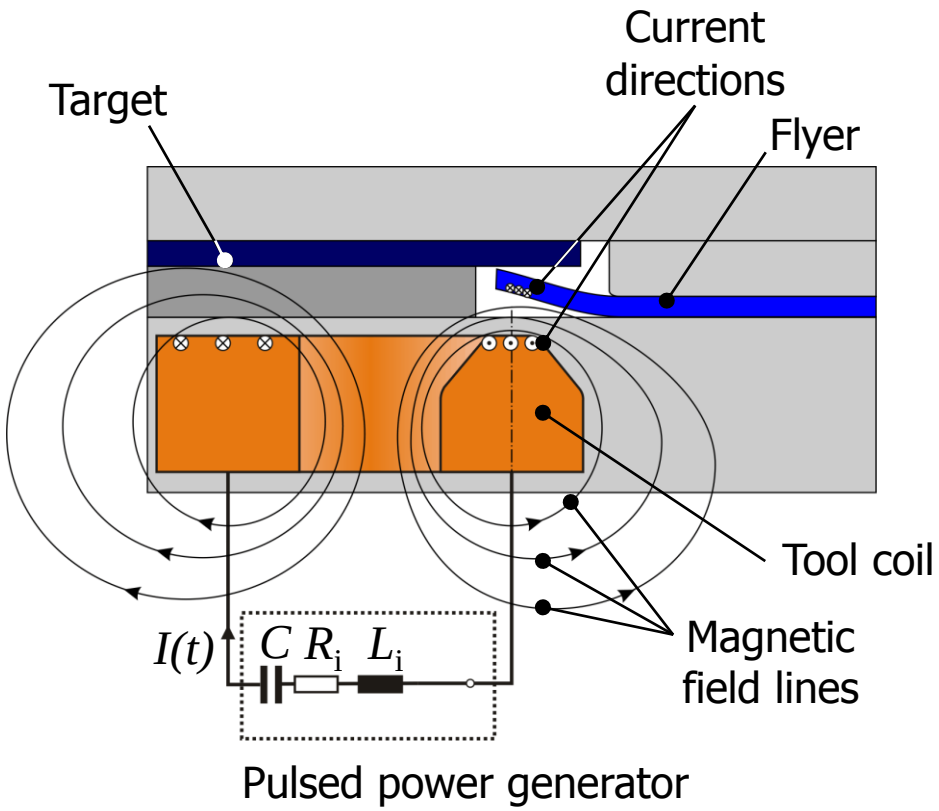
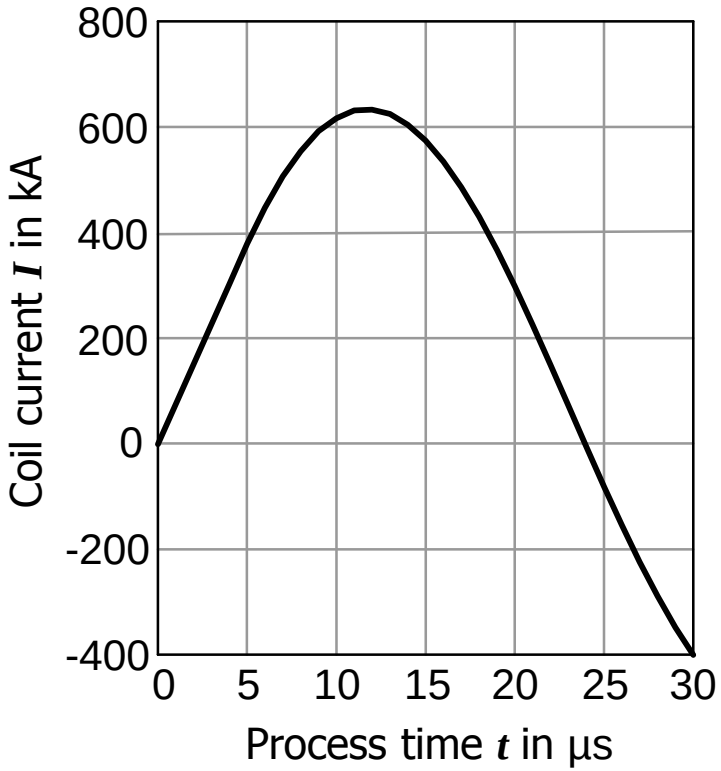
Magnetic pulse welding - process principle

Exemplary setup of a sheet welding process



Course of the coil current



V. Psyk et al., Manufacturing of Hybrid Aluminum Copper Joints by Electromagnetic Pulse Welding, ESAFORM 2017

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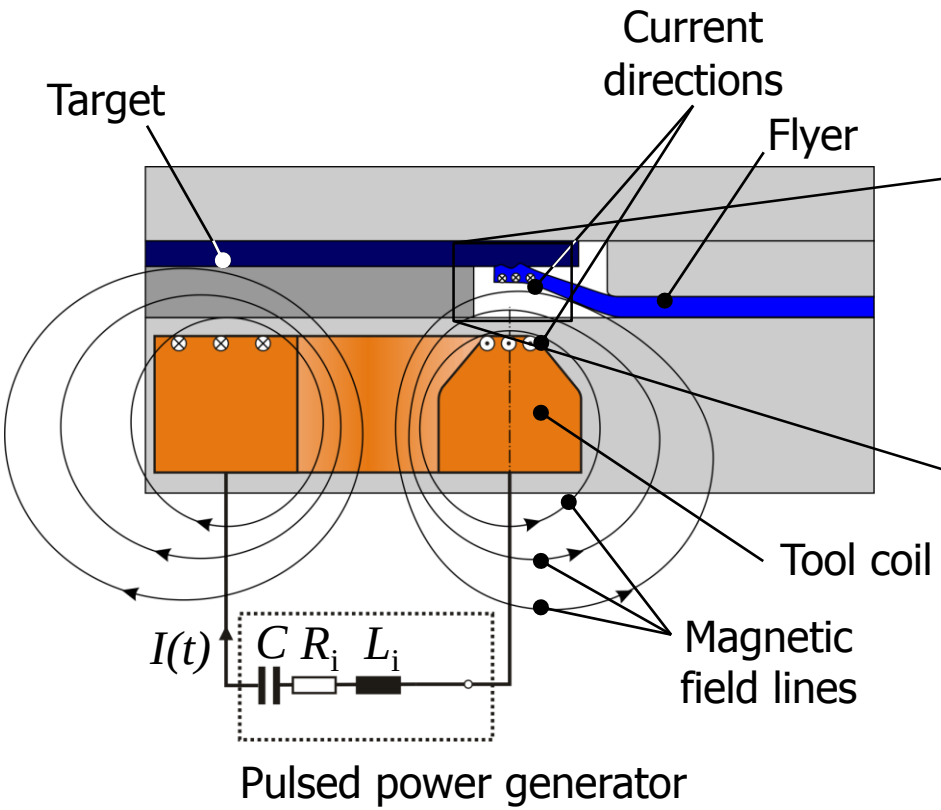
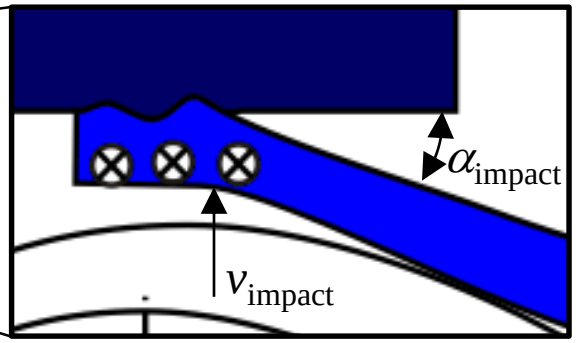
Magnetic pulse welding - process principle

Exemplary setup of a sheet welding process



Collision parameters



Impact angle α_{impact}
Impact velocity v_{impact}

V. Psyk et al., Manufacturing of Hybrid Aluminum Copper Joints by Electromagnetic Pulse Welding, ESAFORM 2017

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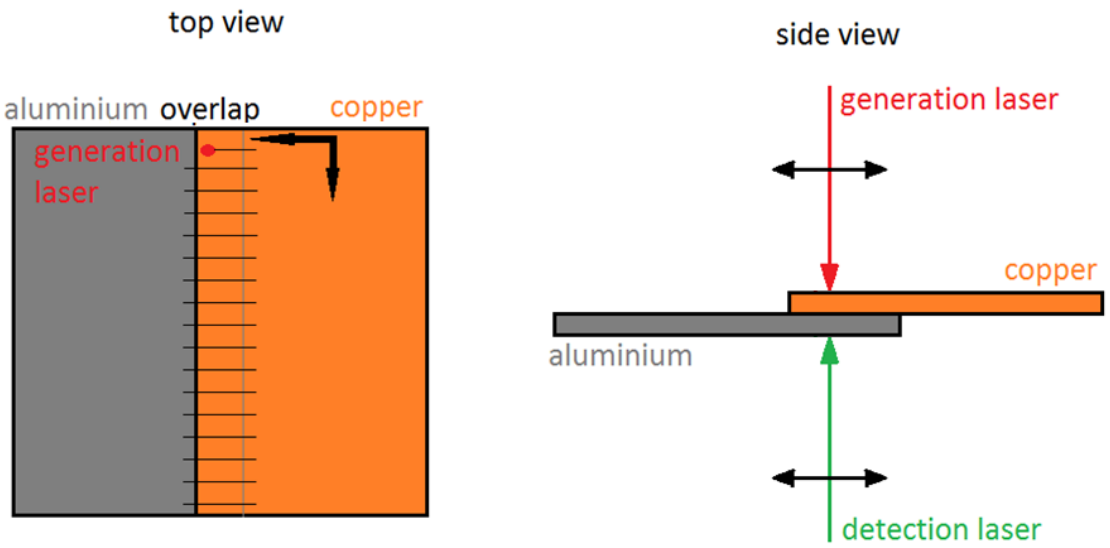
Sheet metal specimen - Setup

Measurement configuration



Experimental parameters:

- Generation laser: nanosecond Q-switched pulse laser (wavelength: 1064nm, 1ns pulse duration, <2mJ/pulse, <2kHz repetition rate)
- Detection unit: two-wave-mixing (TWM) interferometer using a cw laser with 532 nm wavelength

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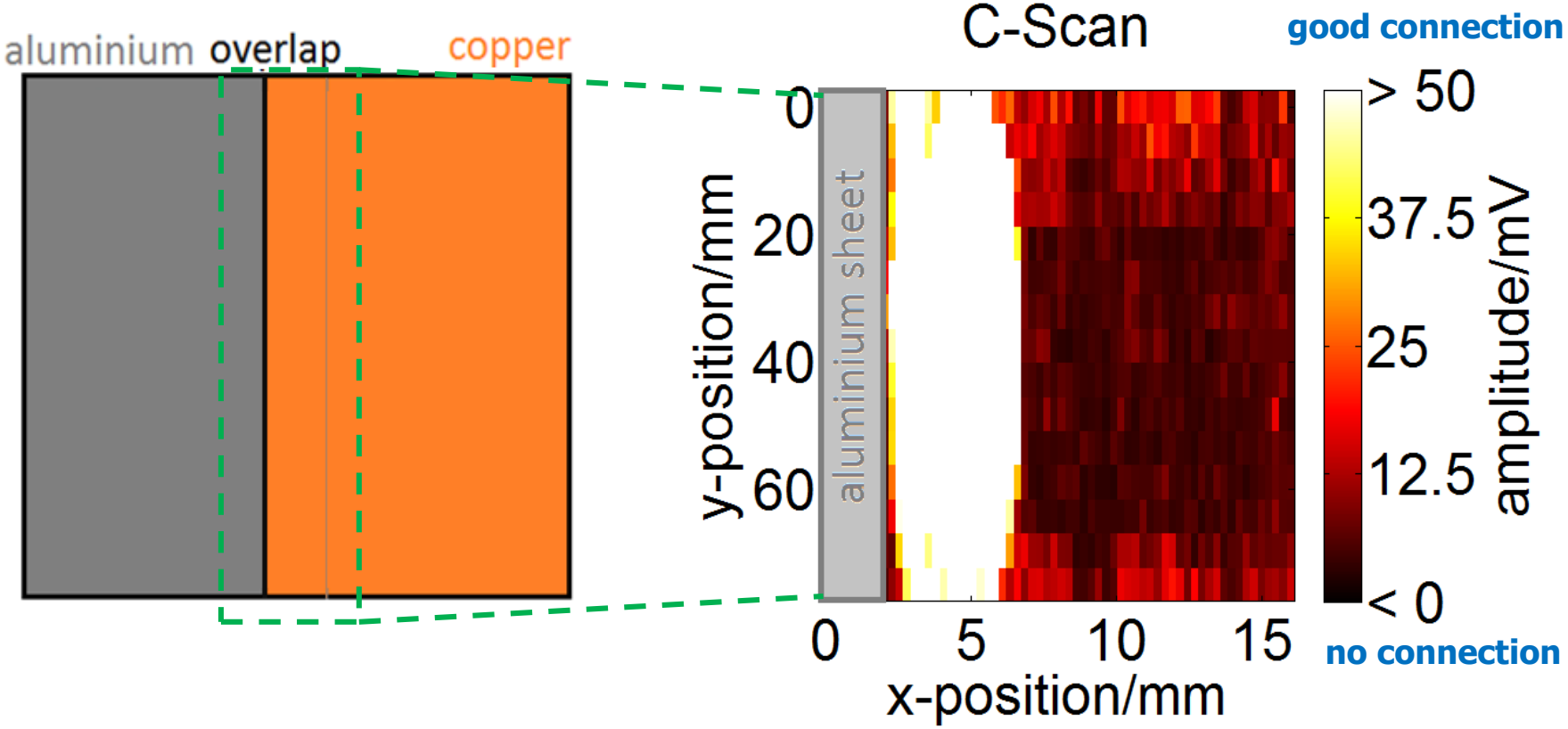
Sheet metal specimen - Results



Spatial resolution for LUS scanning:
Δx <=0.25 mm, Δy = 5 mm

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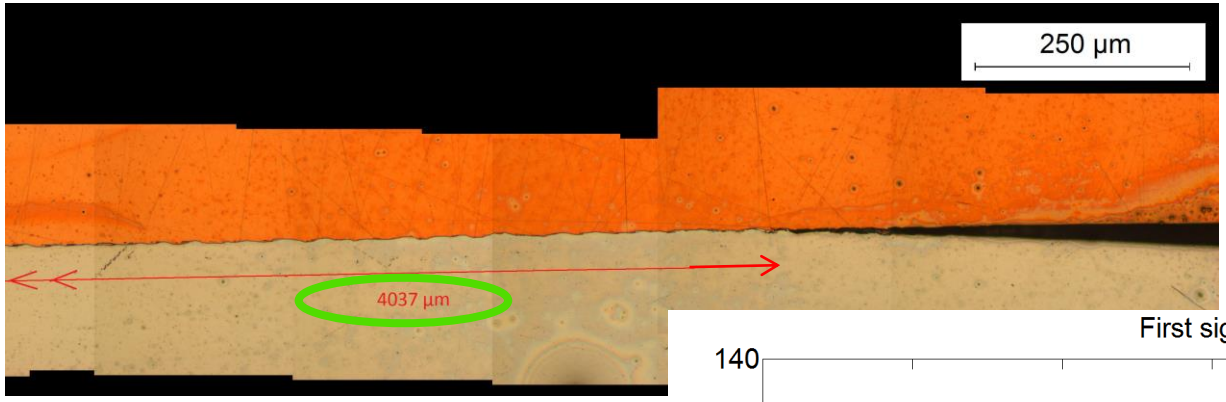
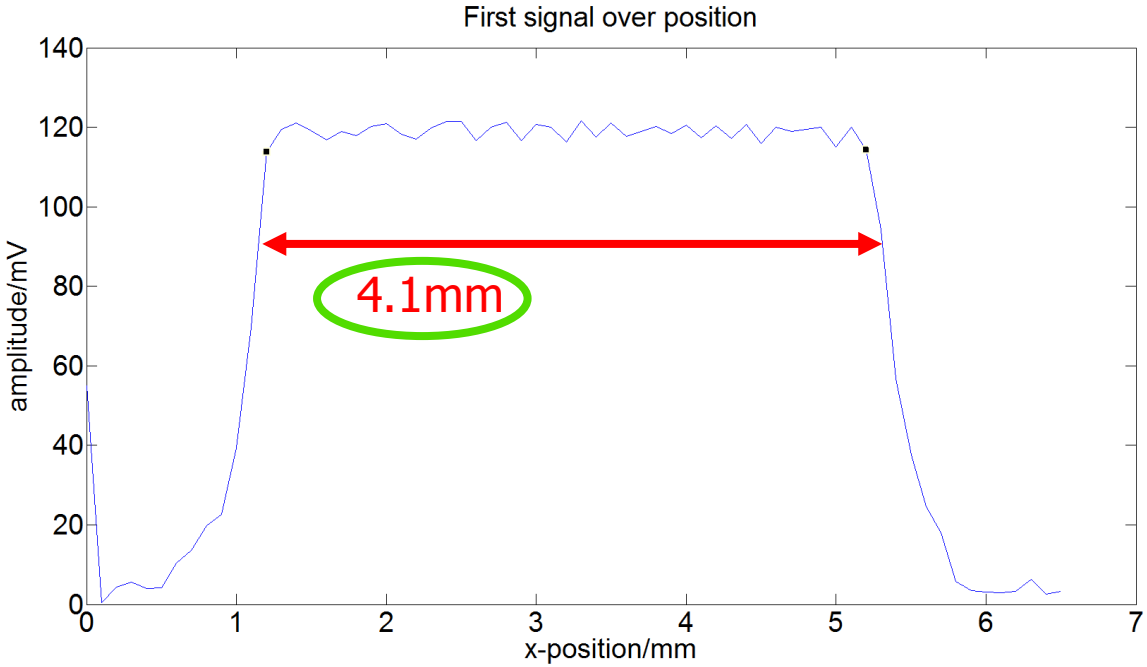
Sheet metal specimen - Results

Comparison with destructive tests - metallography





- Micrograph:
  - Micrographs show a quite good agreement with LUS measurements
  - Definition of threshold level at 75% of maximum amplitude.

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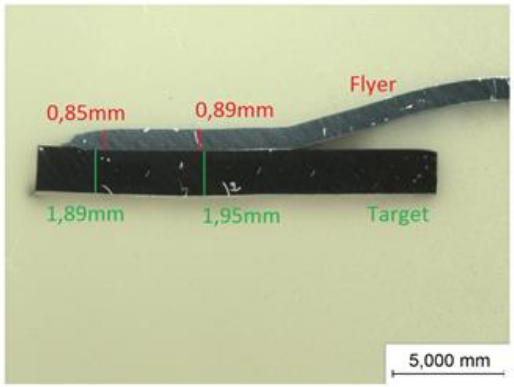
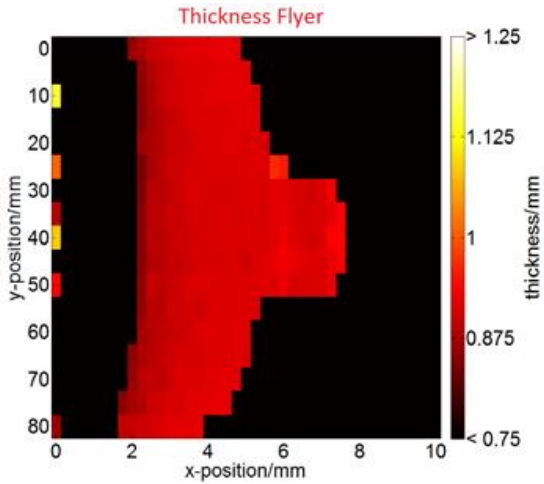
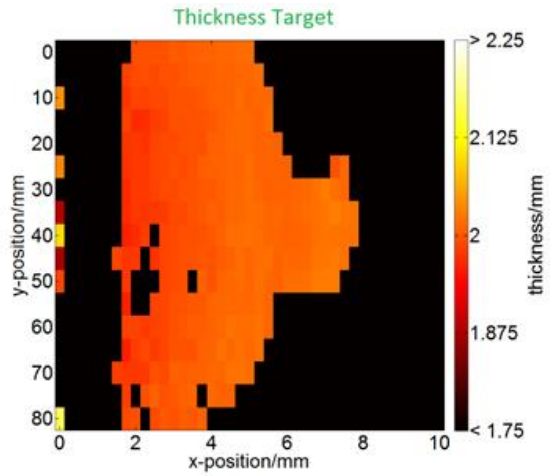
Sheet metal specimen - Results

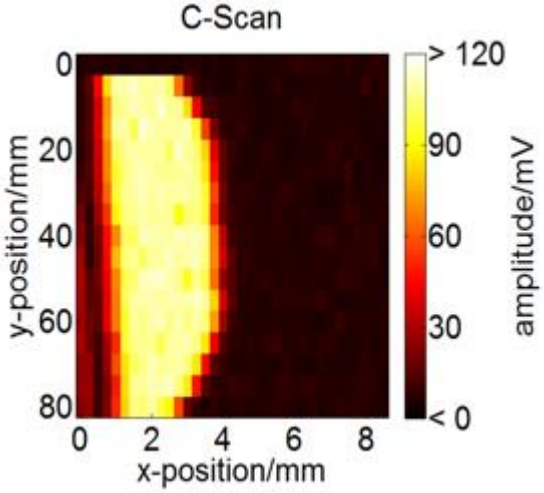
Thickness measurements:







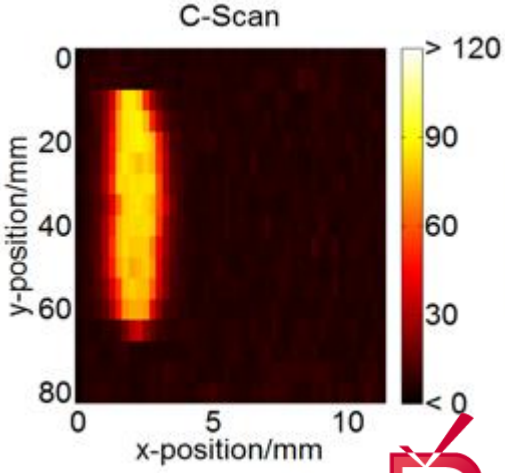
Lap-shear test:



Results from lap shear test:

1500N shear strength

Failure of the base material



Results from lap shear test:

<1000N shear strength

Failure of the joint

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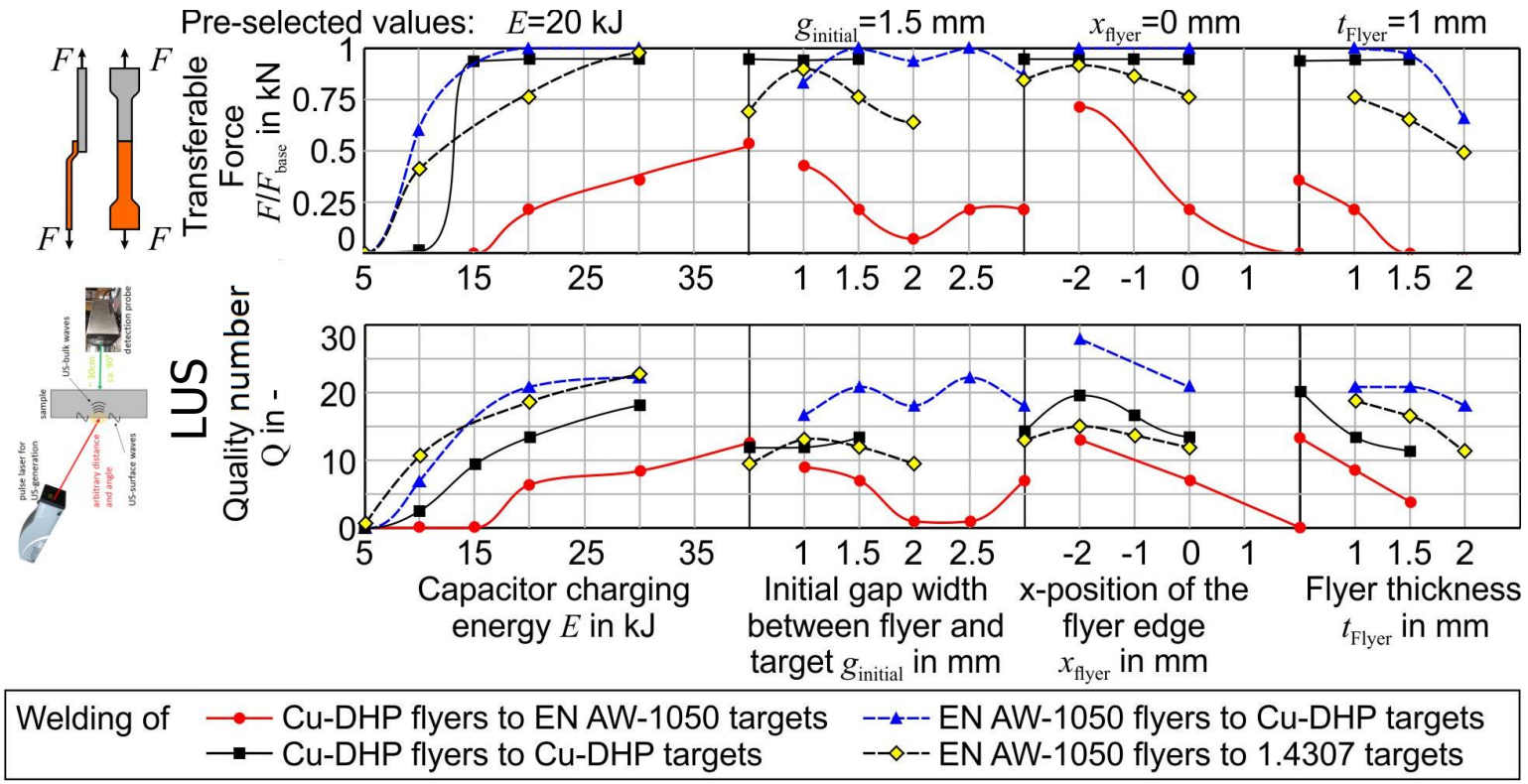
Sheet metal specimen - Results

- Check validity of LUS determined quality number:
  - Very good qualitative agreement of transferable force and quality number



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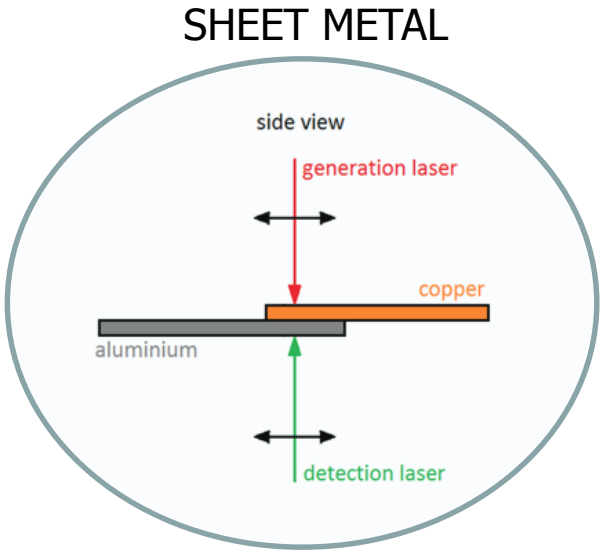
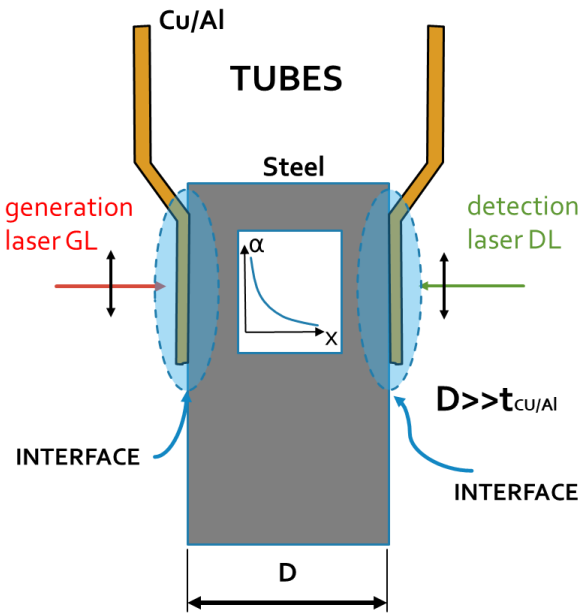
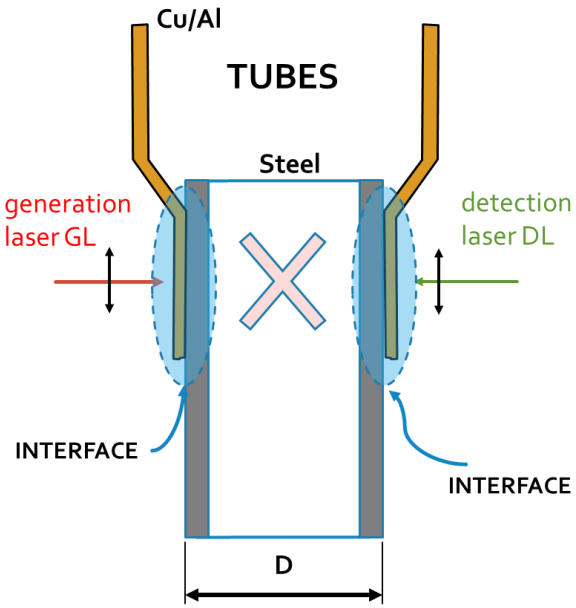
Tubular specimen - Setup







- Due to high absorption α (D>>t) only a weak transmitted US-signal is available on tubular samples
- 2 interfaces cannot be distinguished
- No transmitted US-signal for hollow inner parts

Solution: using backscattered US-signal on the first interface (pulse echo)!

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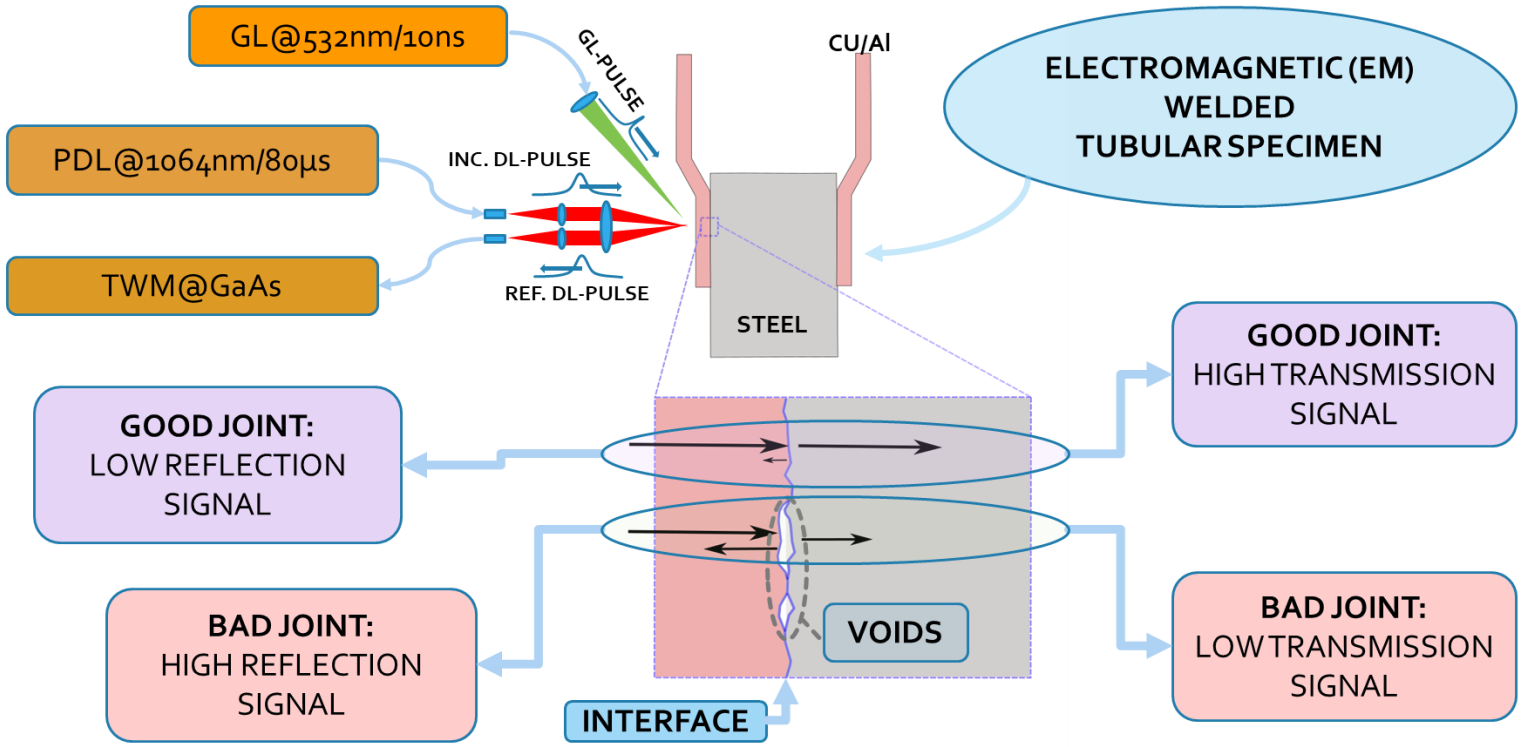
Tubular specimen - Setup



Experimental parameters:

- Generation laser: fiberized nanosecond Q-switched pulse laser (wavelength: 532nm, 10ns pulse duration, energy of 30mJ)
- Detection unit: a pulsed detection laser (PDL, wavelength: 1064nm, 10µs pulse duration, <500 Watts peak power) and a TWM interferometer with GaAs photorefractive crystal

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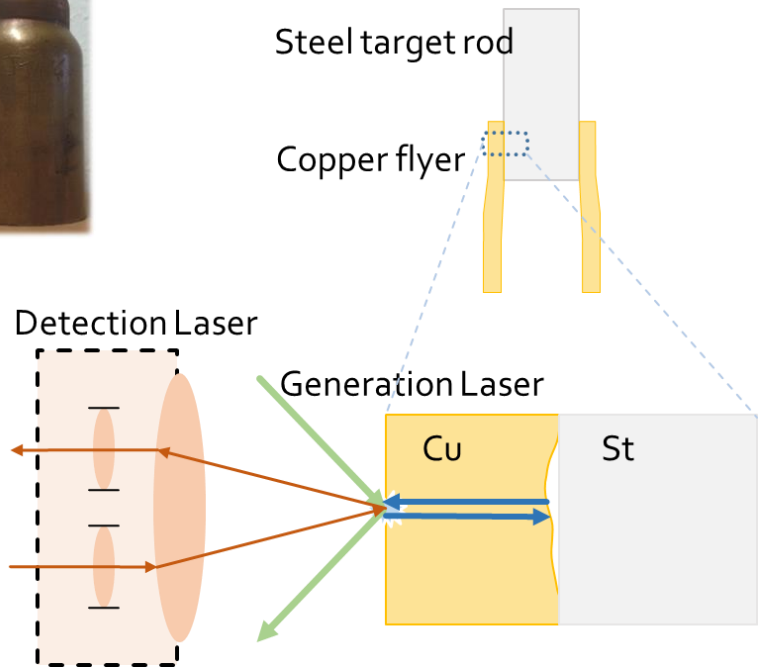
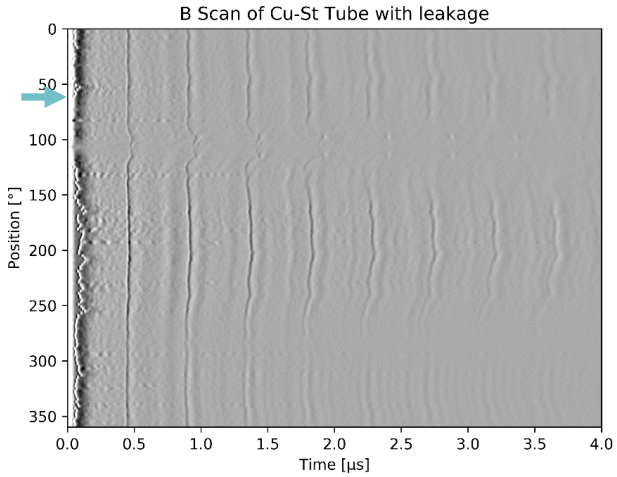
Tubular specimen - Results

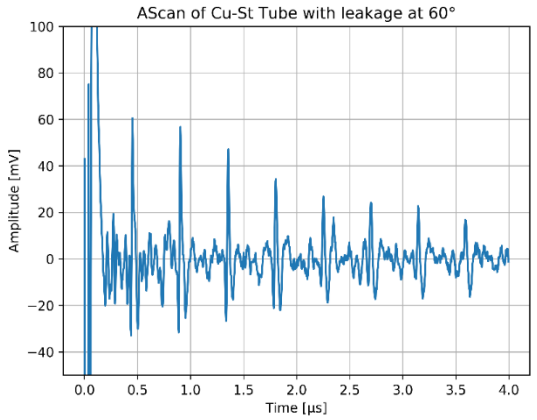
CU-STEEL specimen with large leakage

BAD SAMPLES: LARGE NUMBER OF PULSE ECHOES FROM THE FIRST INTERFACE!





Specimen J114



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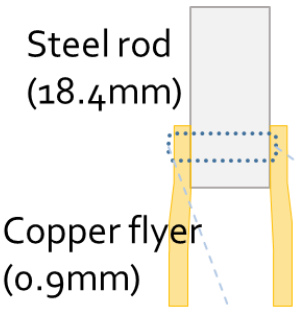
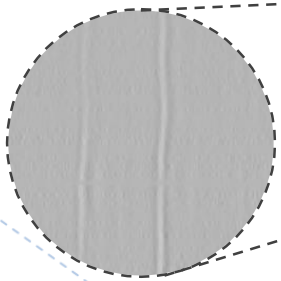
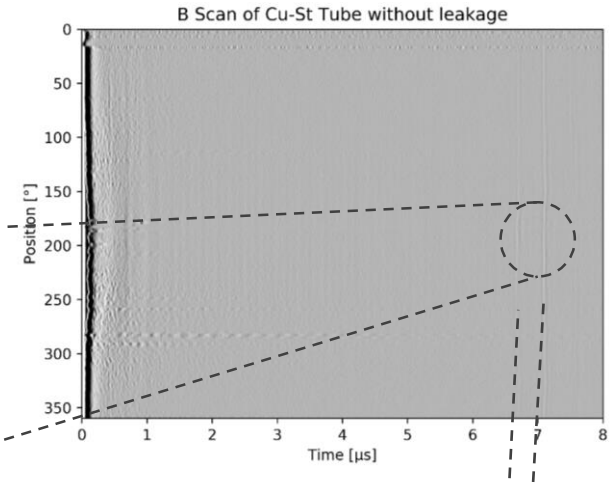
Tubular specimen - Results

CU-STEEL specimen without leakage

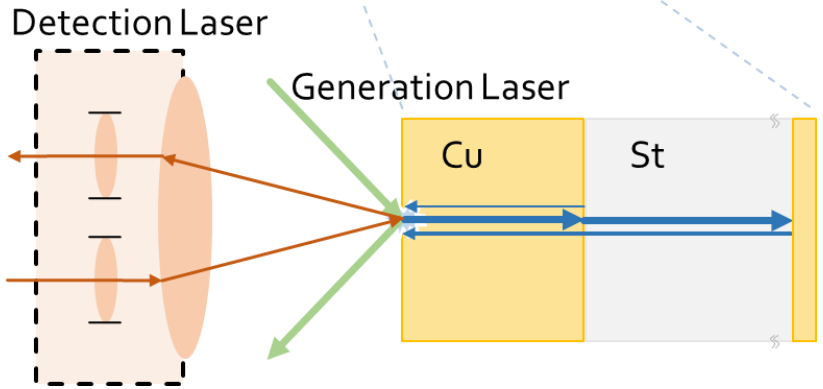
GOOD SAMPLES: PULSE ECHO FROM THE BACKWALL

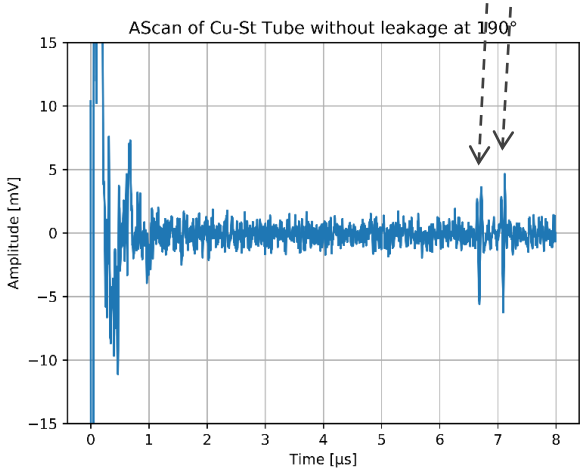






Specimen
JE-CS-R1.18





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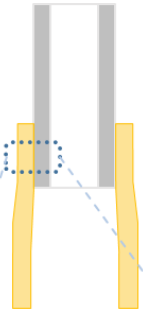
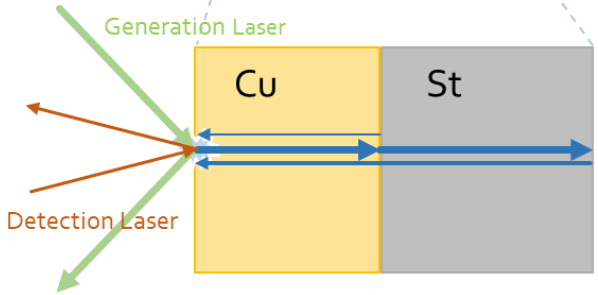
Tubular specimen - Results

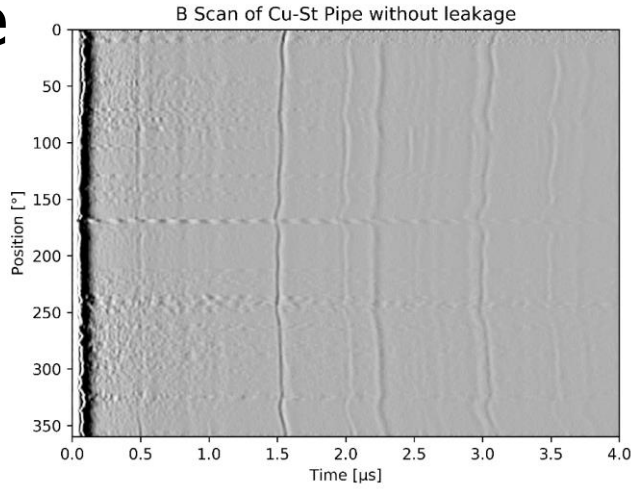
CU-STEEL tube without leakage

GOOD SAMPLES: PULSE ECHO FROM the backwall combined with low echos caused by the interface

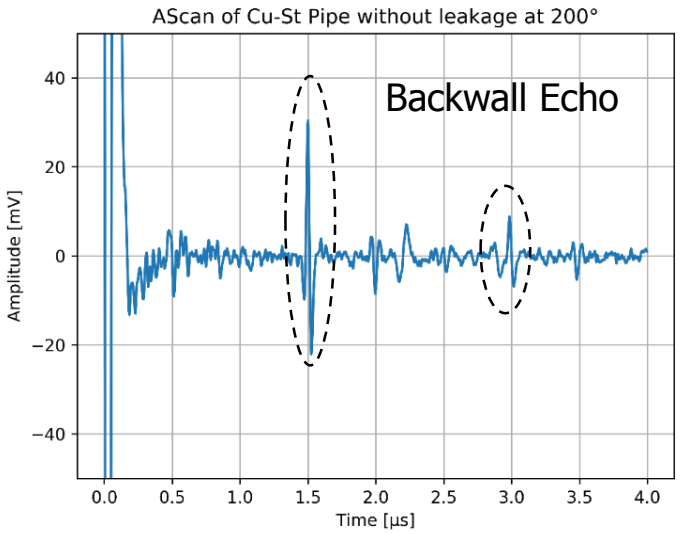


Copper flyer (0.9mm)





Specimen JE-CS-R2.4



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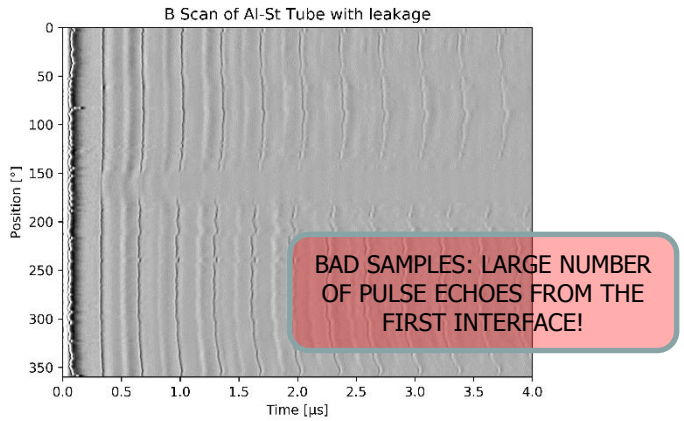
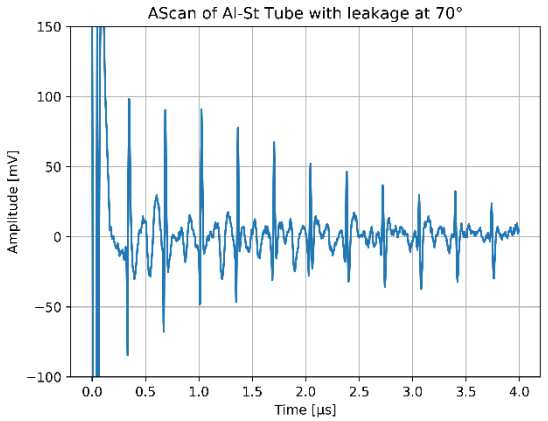
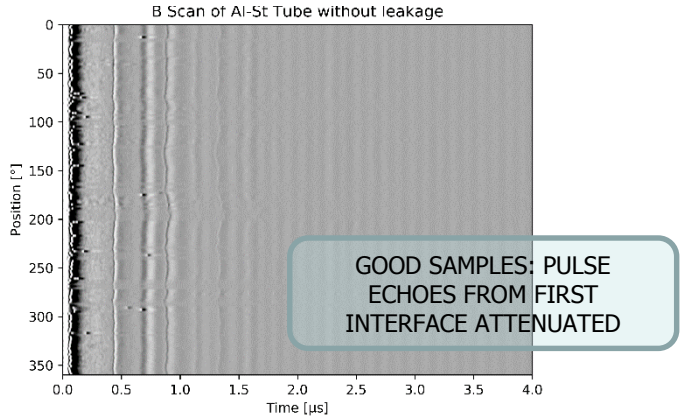
Tubular specimen - Results

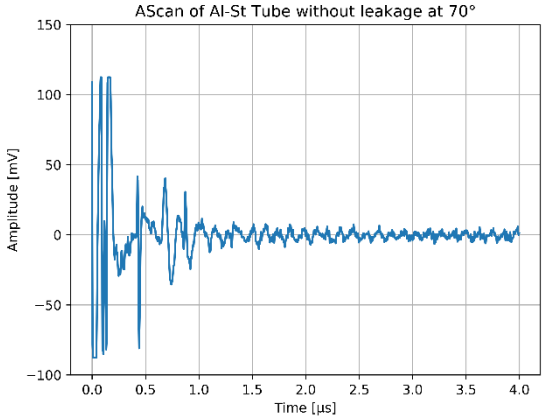
AL-STEEL specimen





Specimen JE-AS-R1.9





Specimen JE-AS-R6-1.3m

Interface is visible for good samples:

$Z_{ST} = 46.6\ 10^6\ kg/m^2s$

$Z_{AL} = 17.0\ 10^6\ kg/m^2s$

$Z_{CU} = 41.6\ 10^6\ kg/m^2s$

$R_{CU\ ST} = 0.3\%$

$R_{AL\ ST} = 21\ \%$

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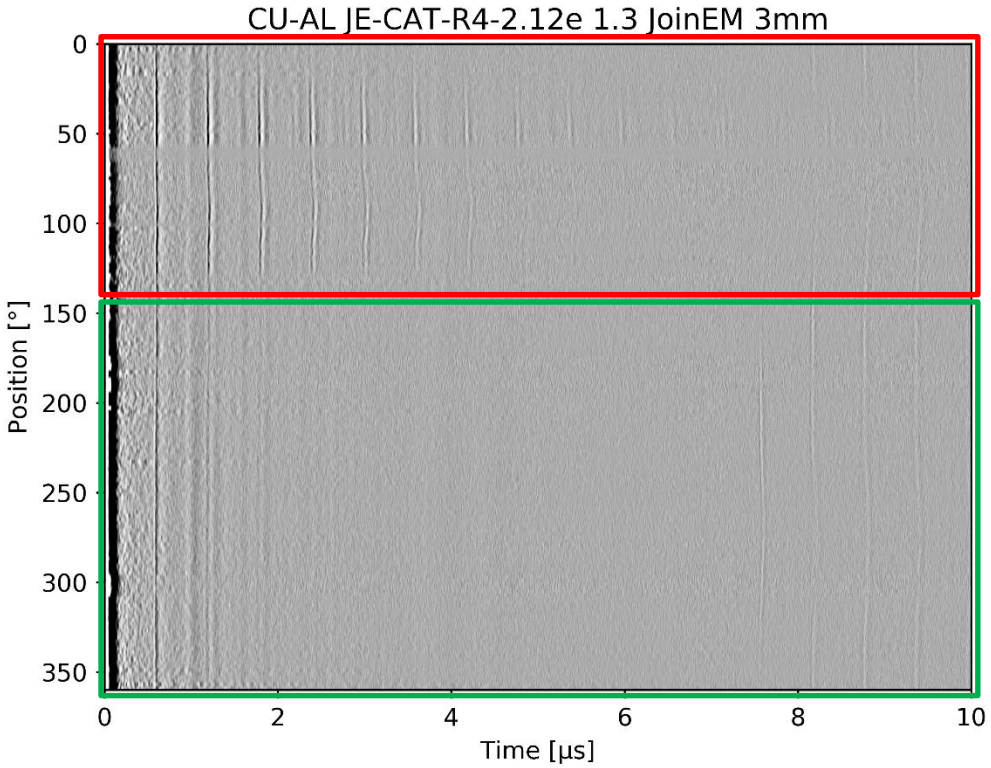
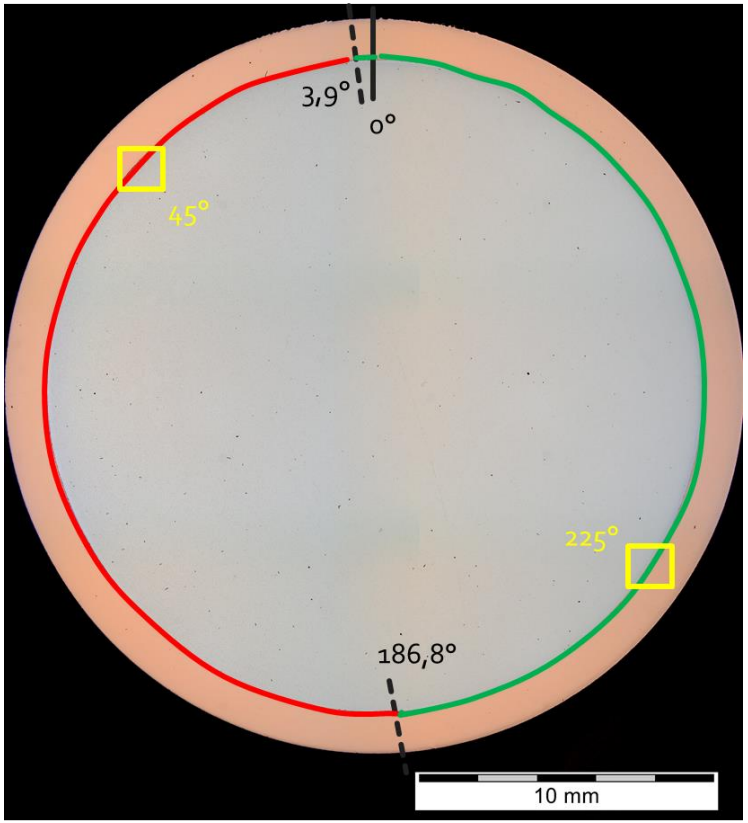
Tubular specimen - Results

Comparision with metallography





Color code:

green: welded zone

red: unwelded zone

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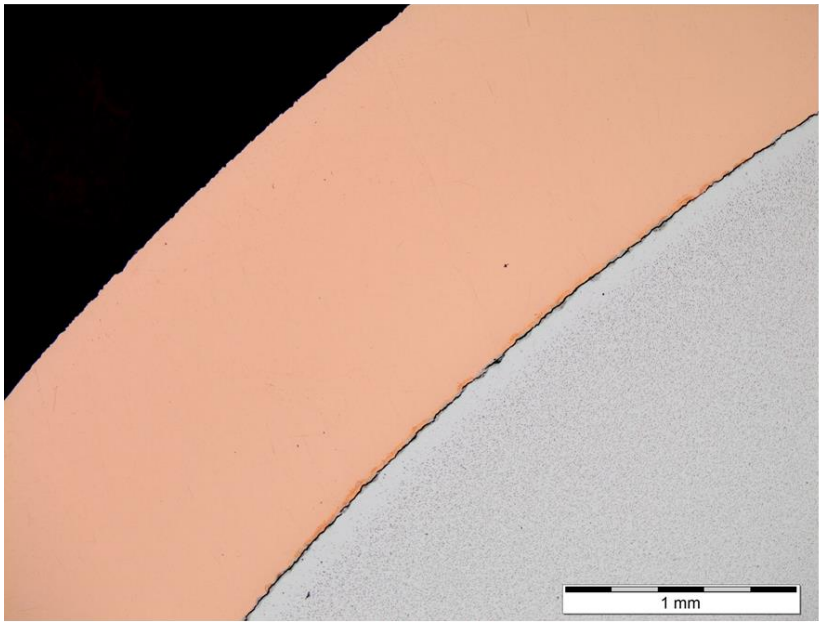
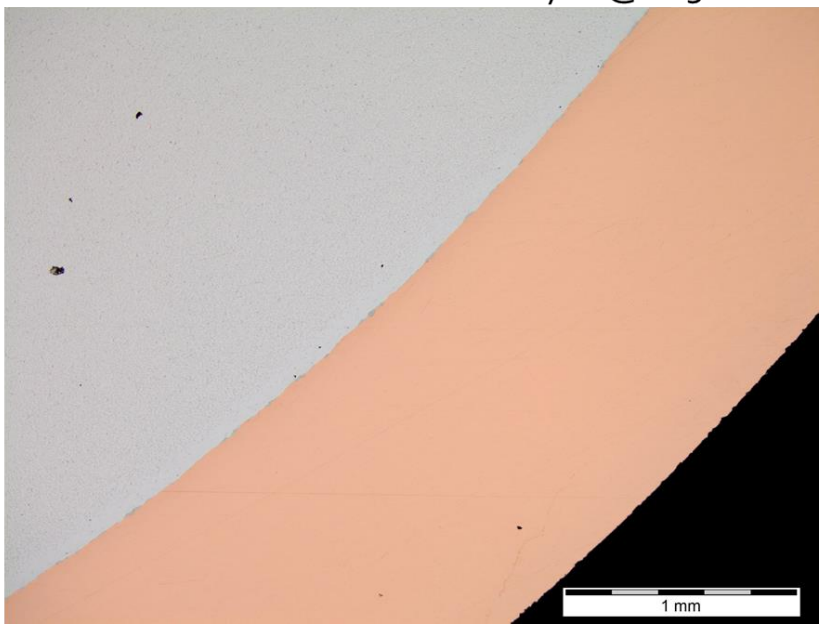
Tubular specimen - Results

Comparision with metallography

Unwelded zone
with remains of interfacial layer @ 45°



Welded zone
without interfacial layer @ 225°



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Summary and conclusion

- Magnetic pulse welding is used for e.g. joining of dissimilar materials
- Two different Laser ultrasound systems have been developed
  - transmission configuration for sheet metal
  - reflection configuration for tubular specimen
- Good and bad samples show different ultrasound signals
- Good agreement with destructive test

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Acknowledgement

- Titel JOINing of copper to aluminium by ElectroMagnetic fields
- Acronym JOIN'EM
- Duration 01.09.2015 - 31.08.2018
- Budget 4.7 Mio. €
- Grant 4.1 Mio. €
- Coordinator Fraunhofer IWU (Dr.-Ing. Verena Psyk)

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