Acoustic methods for manufacturing and quality control: a case study of laser welding of steel

Cristiana Golfetto[1] , Anja Diez[1], Ivan Bunaziv[1], Xiaobo Ren[1], Tonni Franke Johansen[1], Martin Albertsen Brandt[1], Mathias Perskaas[2], Skule Edvard Smørgrav [2], Pål Tuset [2], Espen Elvheim [2]
[1]SINTEF, [2] Force Technology

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Motivation

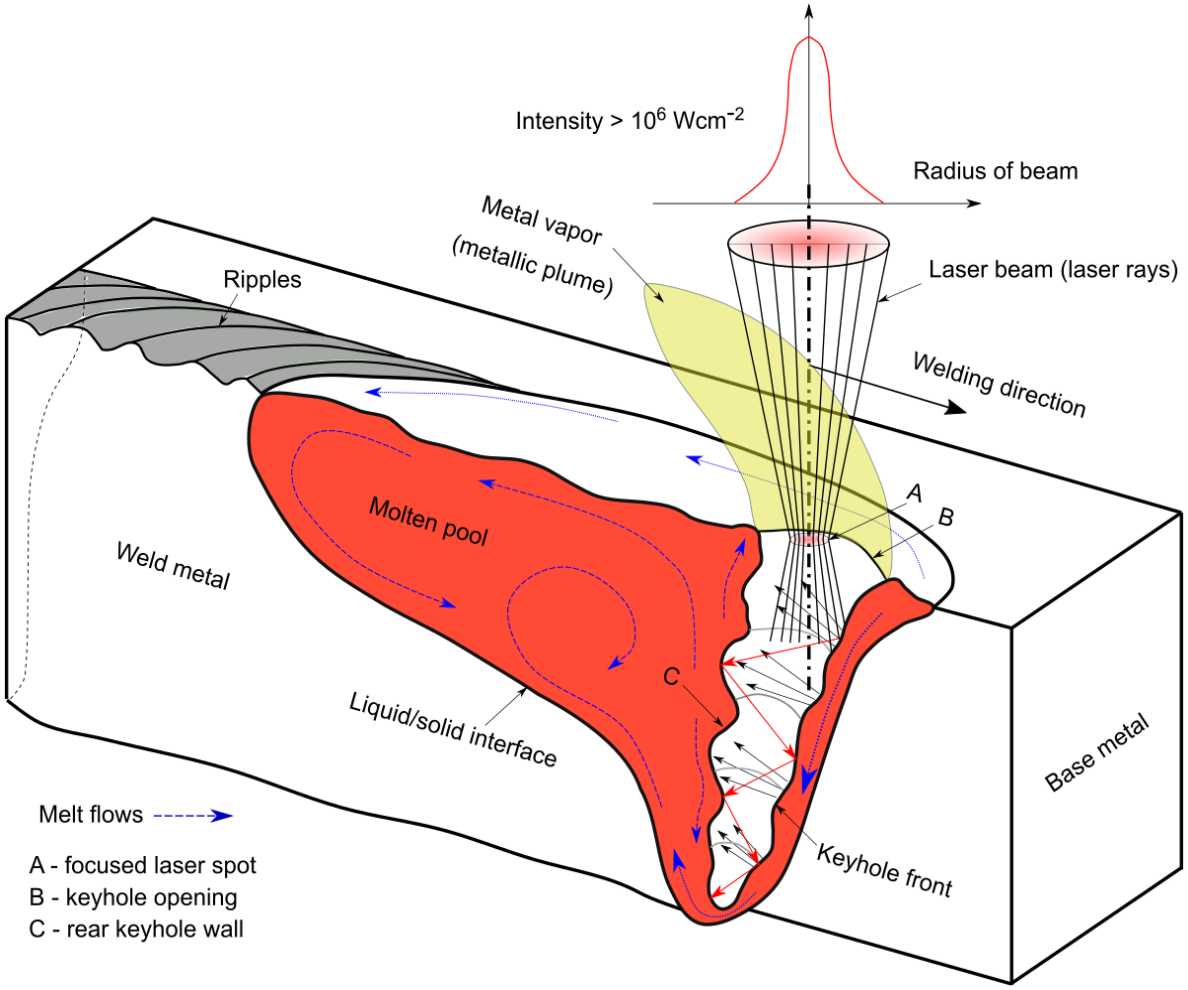
Mass production of offshore wind structures and components

Large-scale deployment of offshore wind farms

Goal: Improve productivity and reduce cost

Laser-based welding: Increased productivity by more than 5-24 times compared to arc welding

Laser welding



Challenges:

Deep keyhole susceptible to instabilities

High temperatures

Intensive and dangerous laser emissions

Fast cooling rates may cause cracking

Record data while the process is undergoing

Research question:

What produces sound and which defect is it?

Acoustic measurement methods

Acoustic emissions (AE)

- passive
- listen to the sounds
- simple methods
- challenging to identify/localize

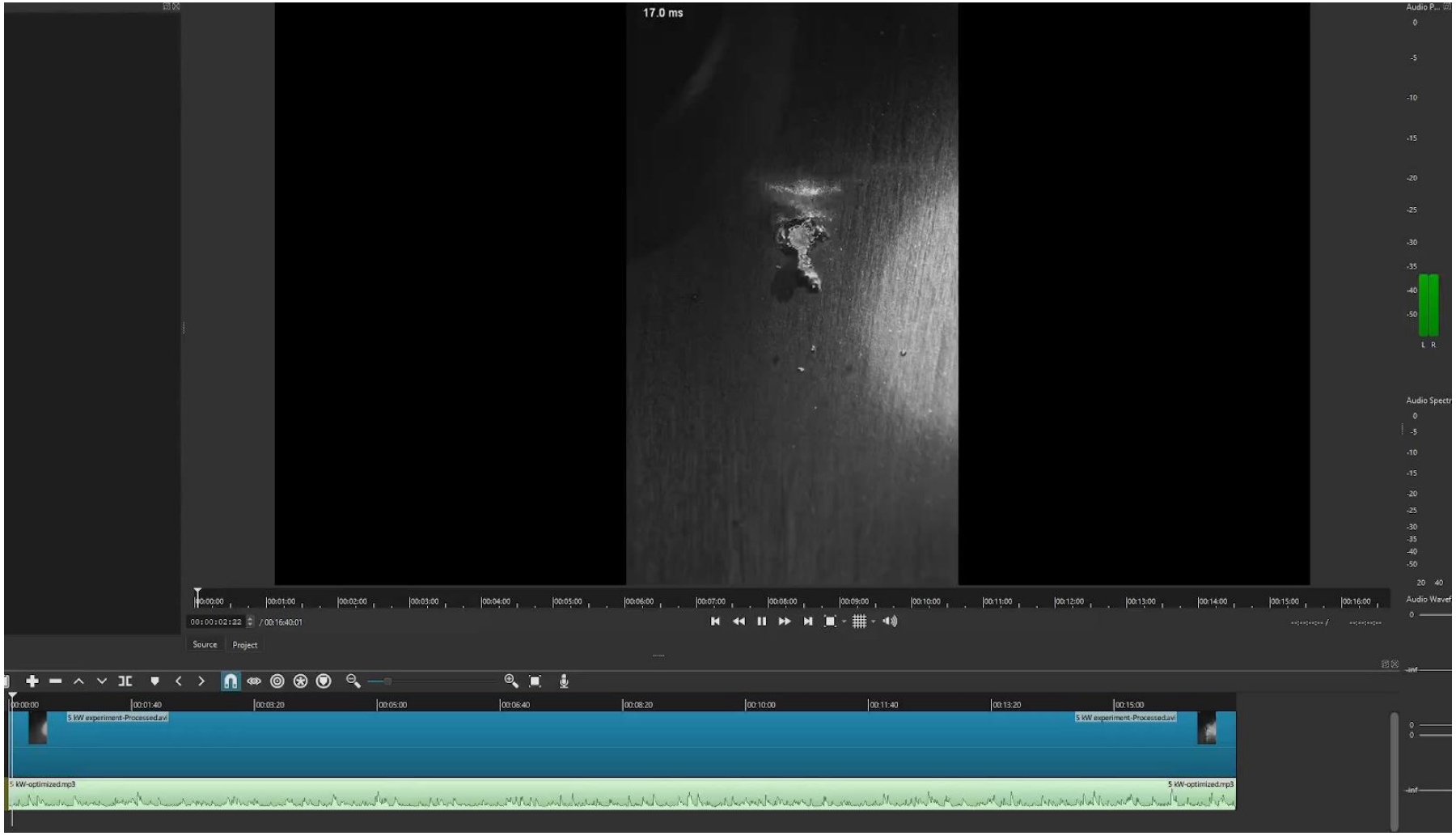
Vibration sensors

Ultrasound (US)

- active
- send/receive pulse
- possible to map/identify/localize
- challenging measure during process

Ultrasound sensors

High Speed Imaging and Acoustic emissions



Vibration sensor data

10 000 frames per second

Acoustic emission data

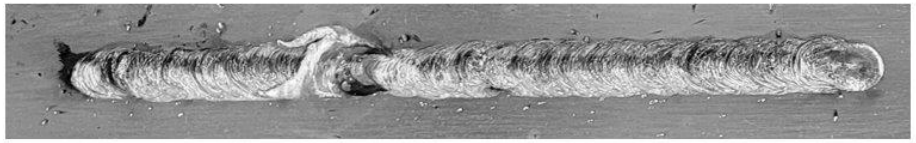
aluminium plates, 20 mm thick

Vibration sensor next to the weld (15-20 cm)

Start

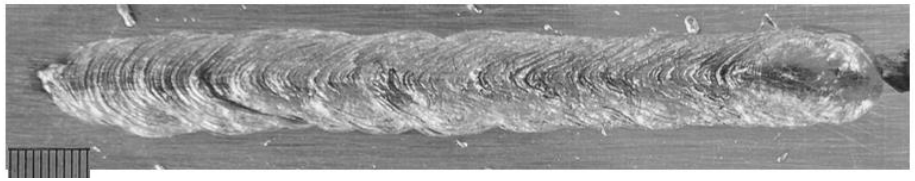
Stop

Laser power 5 kW



Laser power 9 kW

Laser power 12 kW

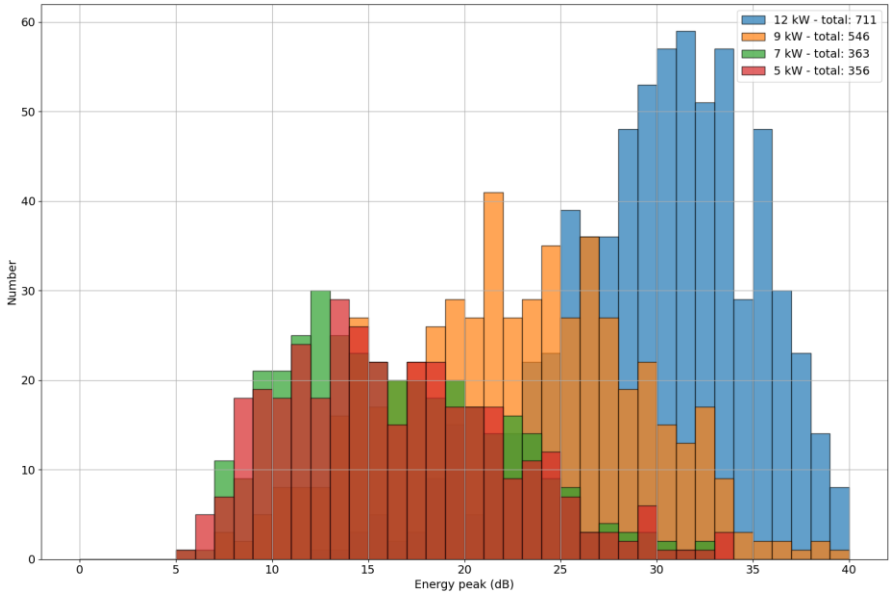


Acoustic emission analysis

Increase in laser power

→increase in amount of AE signals

→increase in strength of signals



Correlation with modelling

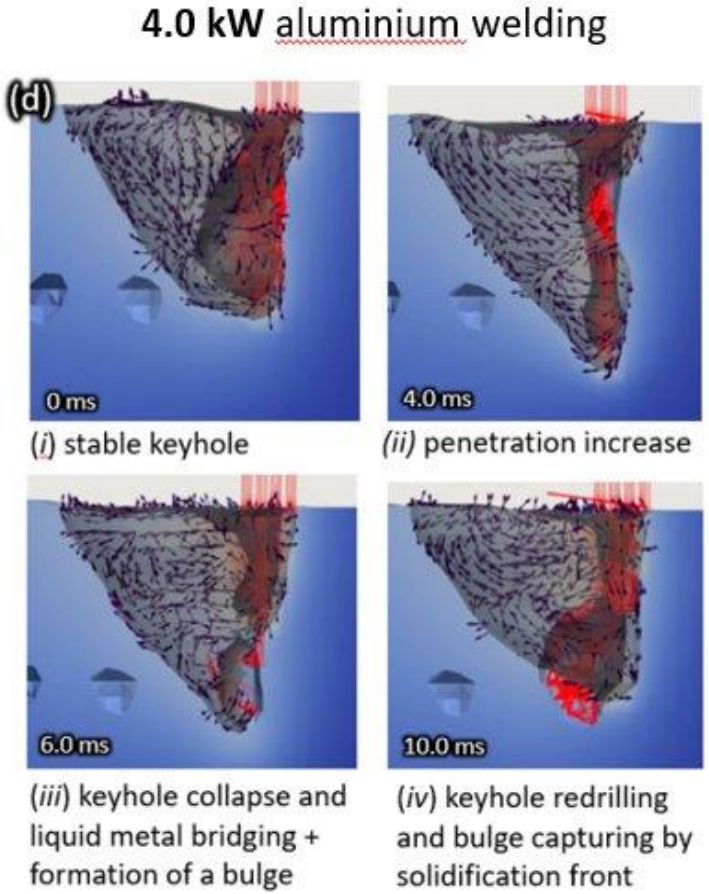
→Keyhole shape changes

12 kW -> 8 ms cycle

9 kW -> 11 ms cycle

7 kW -> 16 ms cycle

5 kW -> 16 ms cycle



Ramp test

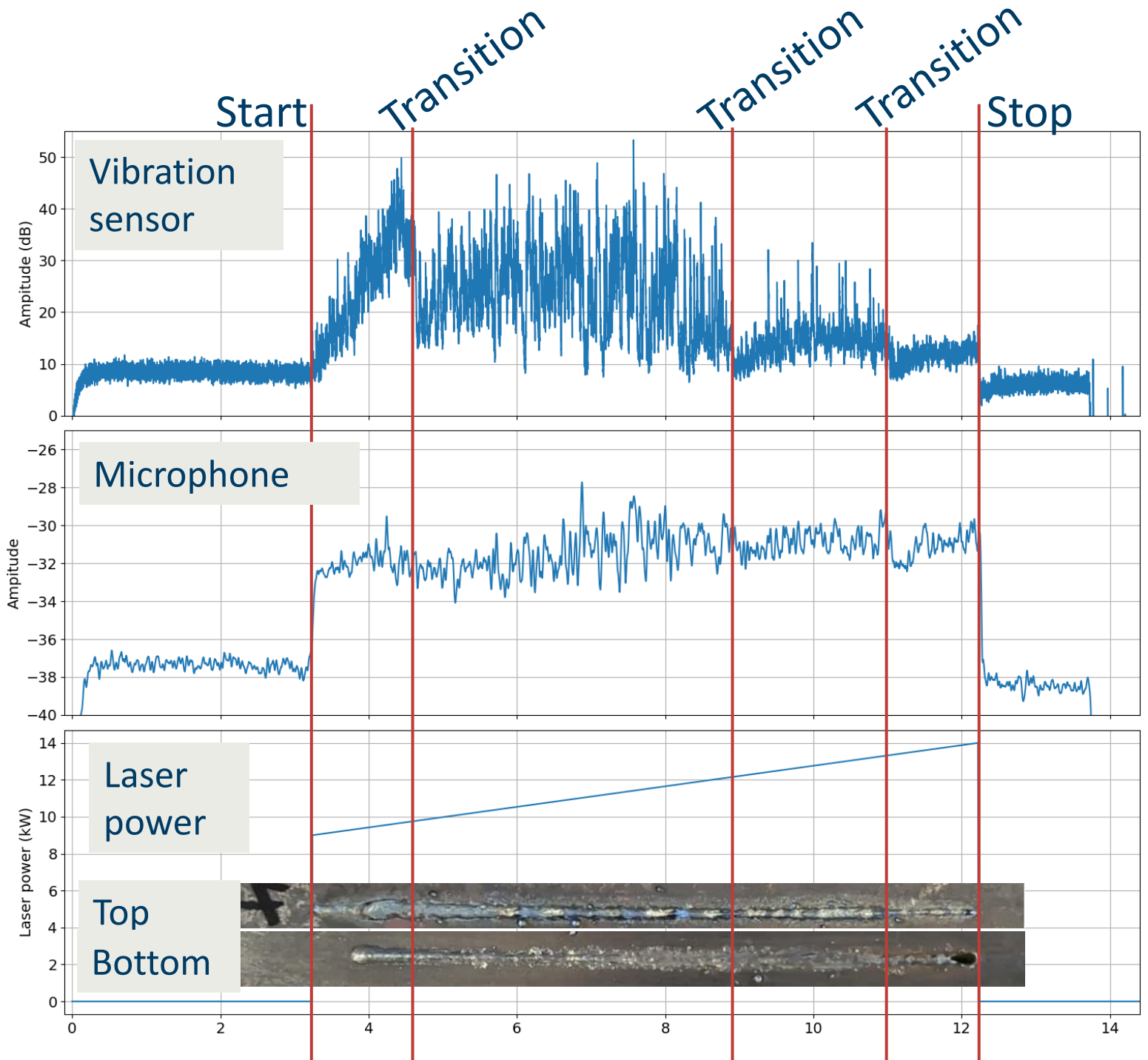
Plate: Steel, 12 mm thick

Laser power: 9 – 14 kW

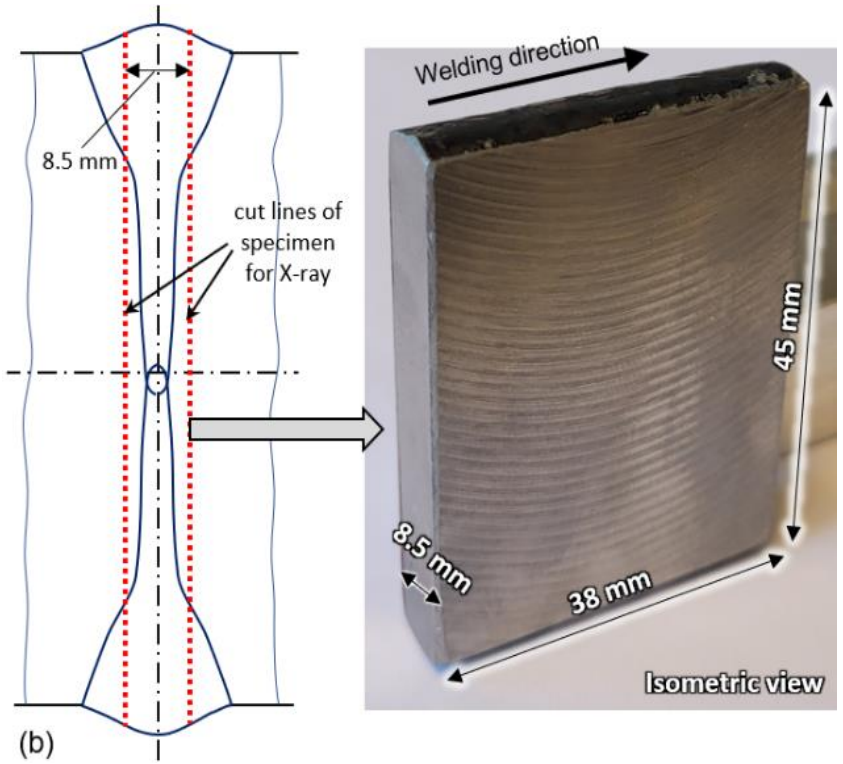
Weld length: 15 cm

Clear transition visible

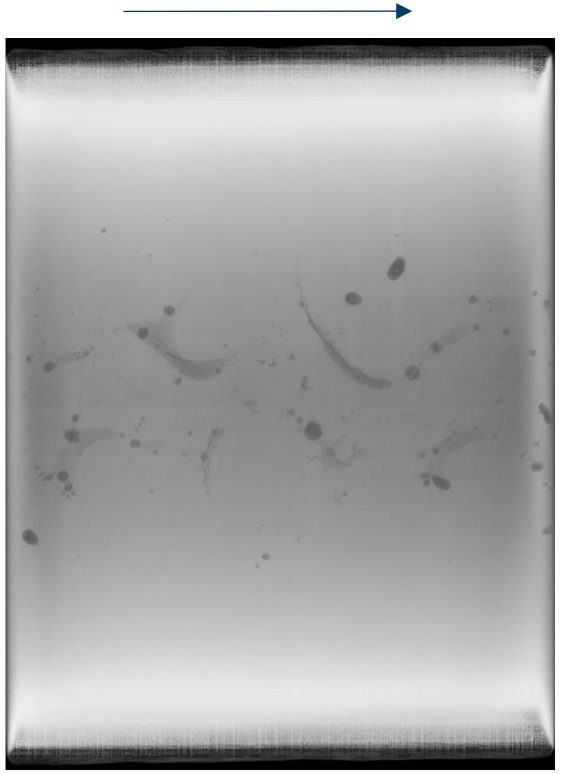
Correlation with images of the plate



Example of solidification cavities in root area



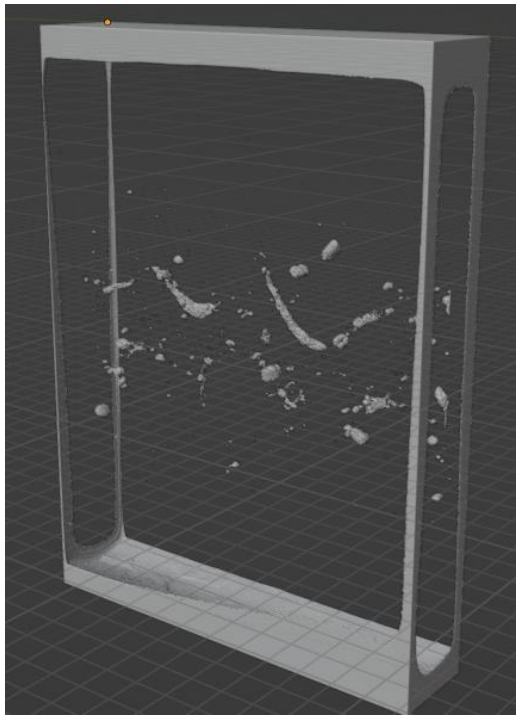
X-ray µCT scanning



38 mm

Multiple transparent overlay provides high resolution. 'Boomerang'-shaped cavities

View perpendicular to weld seam



Reconstruction in 3D space. Thin solidification (100-400 µm in width) cavities are visible

PhysMet

Time of Flight Diffraction (TOFD)

Lateral Wave (LW)

Back-Wall Echo (BWE)

Diffracted energy from the **tips of a defect**

High scanning speed

High accurate defect sizing

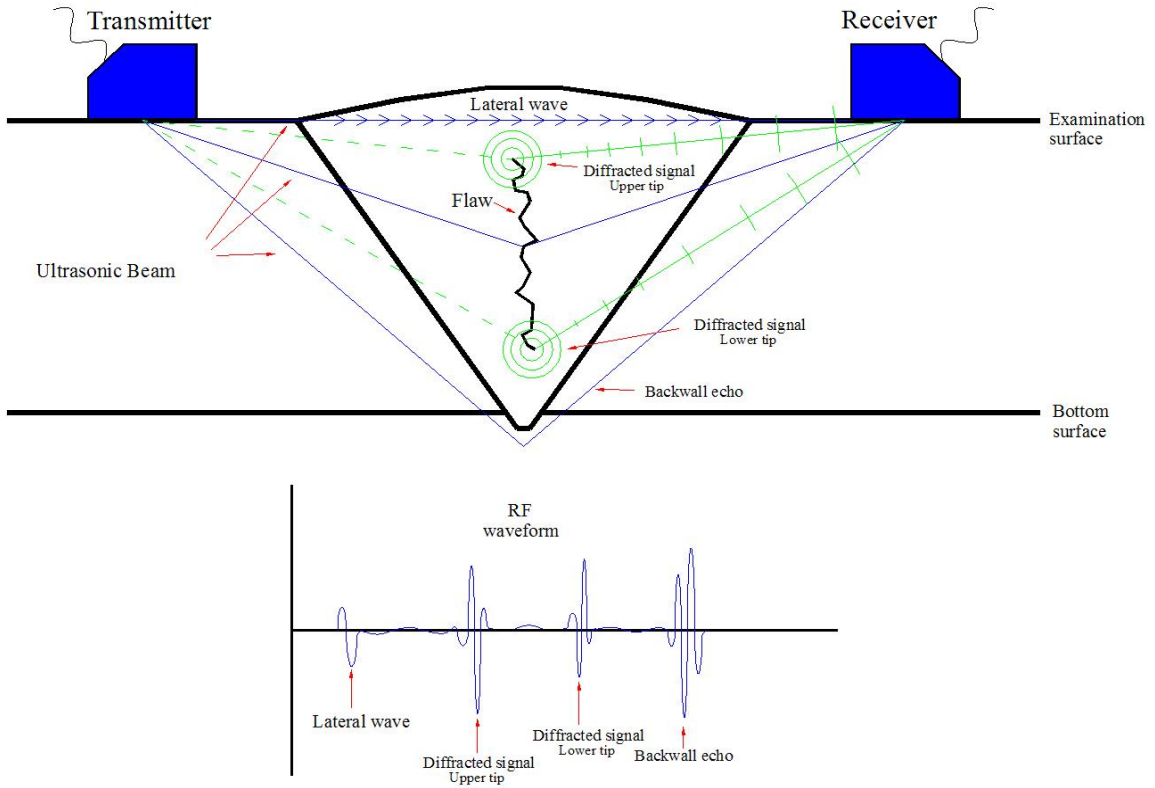


Figure from TOFD - AUT Solutions

What was done: TOFD – Laser welding

Plate: Steel, 45 mm thick

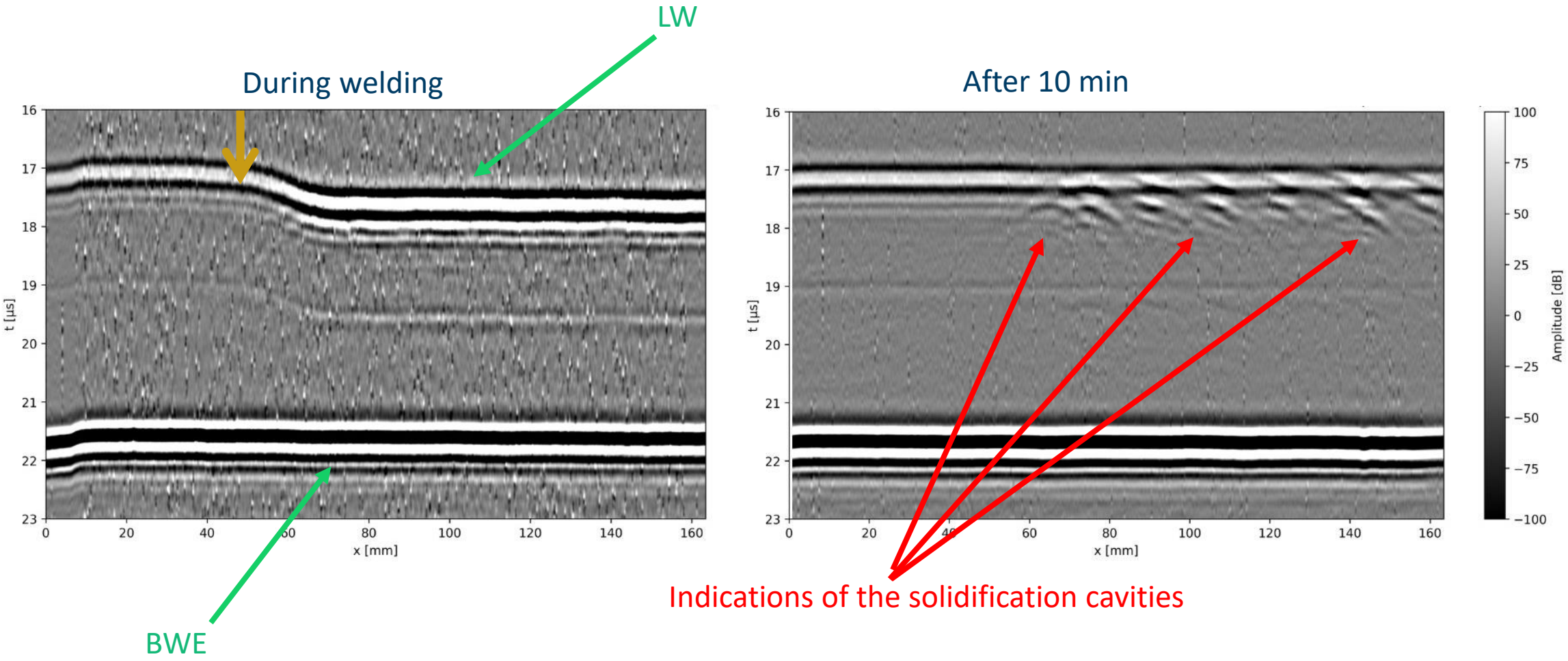
Laser power: 14 kW

Sampling rate: 60 MHz

Distance between transducers: 104 mm

Probes placed approx. 50 mm behind laser start and laser stop

Results

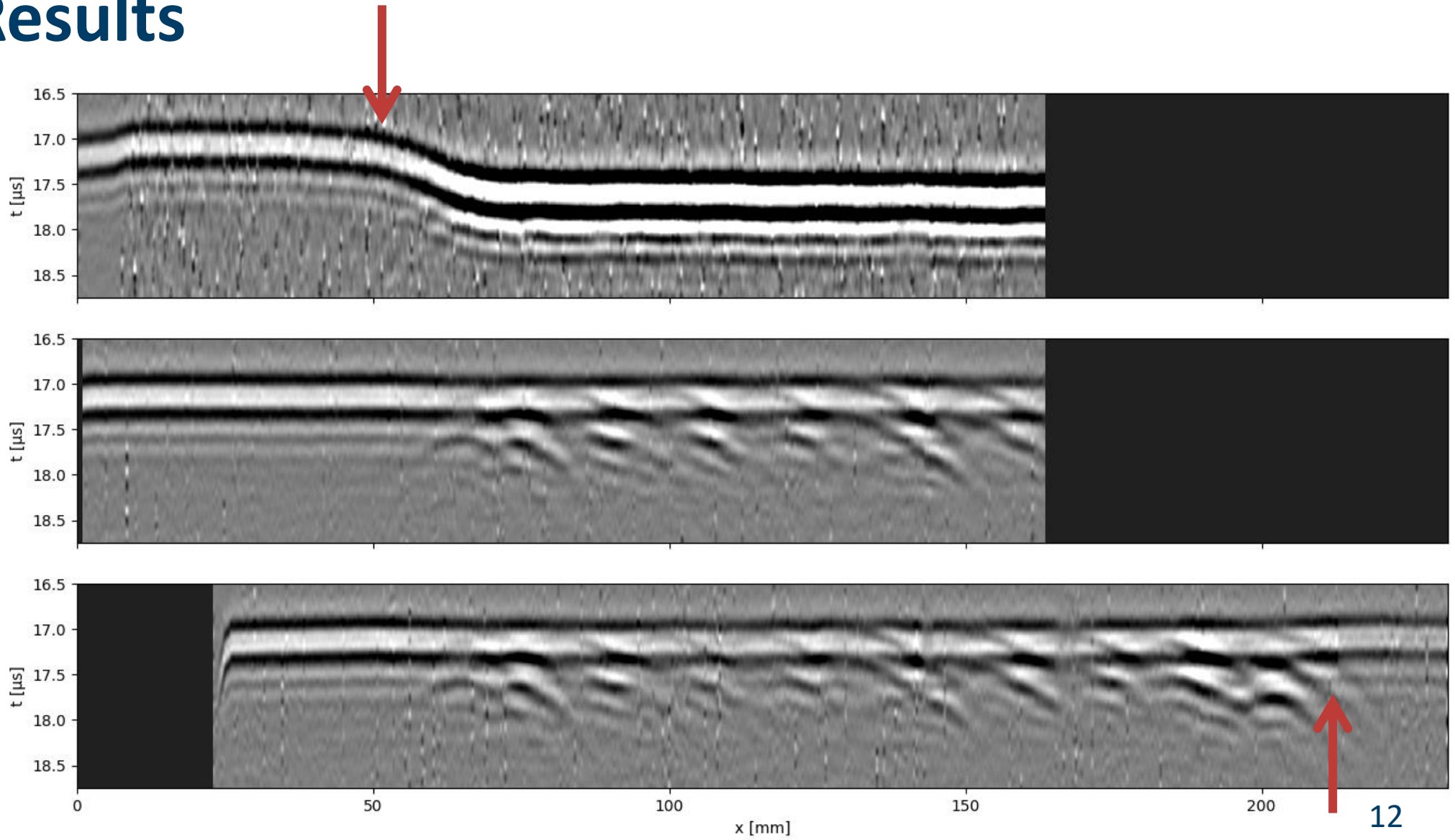

LW
During welding
After 10 min
t [µs]
x [mm]
Amplitude [dB]
BWE
Indications of the solidification cavities

Results

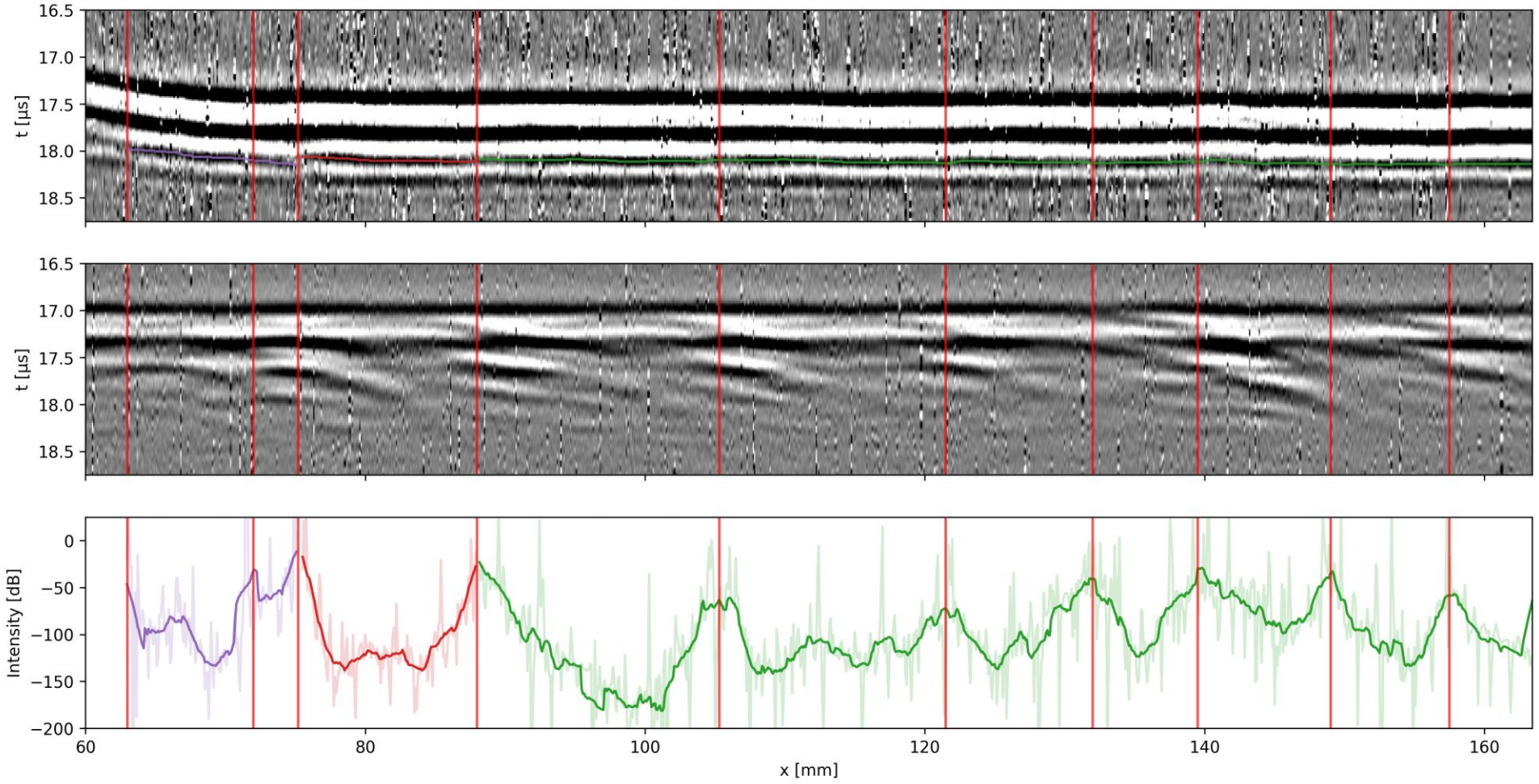
During welding

After 10 min

After 20 min



Results


16.5
17.0
17.5
18.0
18.5
t [µs]
16.5
17.0
17.5
18.0
18.5
t [µs]
0
−50
−100
−150
−200
Intensity [dB]
60
80
100
120
140
160
x [mm]

Conclusions

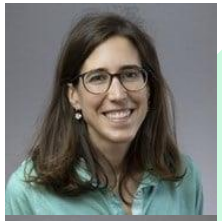
Susceptibility of deep keyhole to instabilities identified, live data recorded

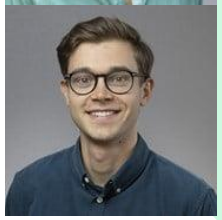
Correlation between laser power and AE strength

Correlation between peaks in intensities in live data and locations of solidification cavities

Acoustic methods -> potential to support **high quality welding and robustness** of **mass production of offshore wind structures**

Project team, SINTEF and Force Technology



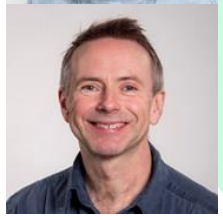


Mathematics and Cybernetics
Digital

Cristiana, Martin
Ultrasound, Robotics

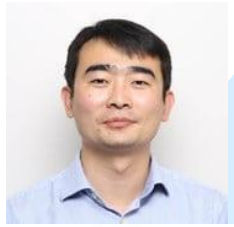
Materials and Nanotechnology
Industry

Ivan, Morten
Laser Welding



Acoustics SCT
Digital

Anja, Tonni
Acoustic Emission



Metal production and processing
Industry

Kai, Xiaobo
Additive Manufacturing

Turning wind R&D into export industry that creates green jobs and respects nature