QWELD

QUALITY ASSURANCE OF LASER WELDS

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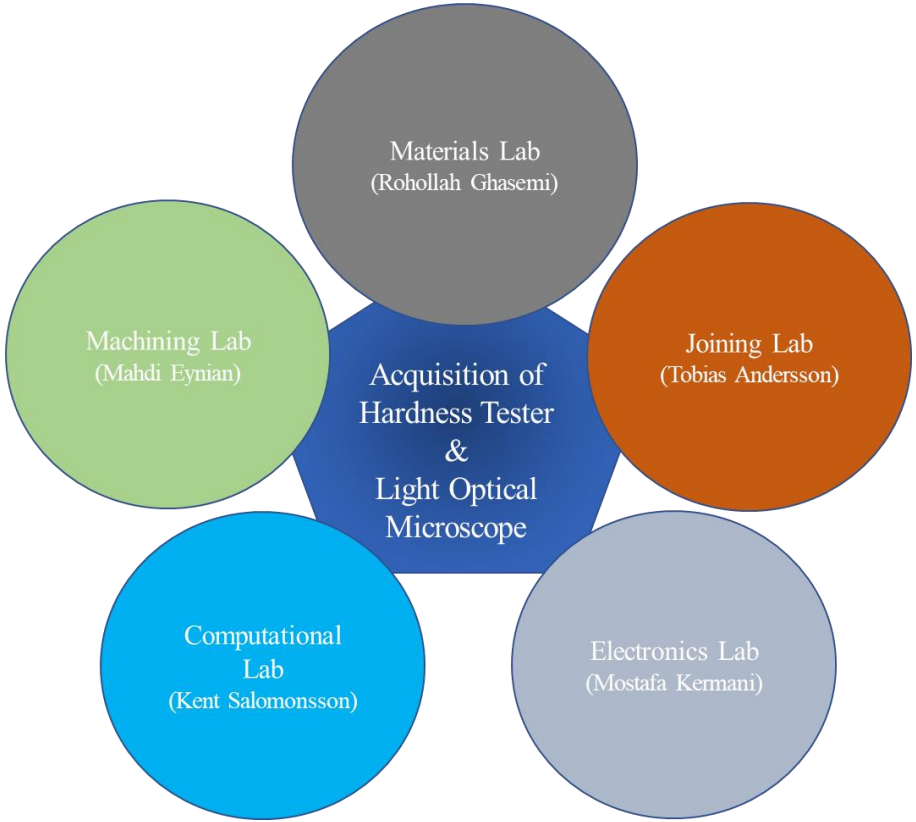
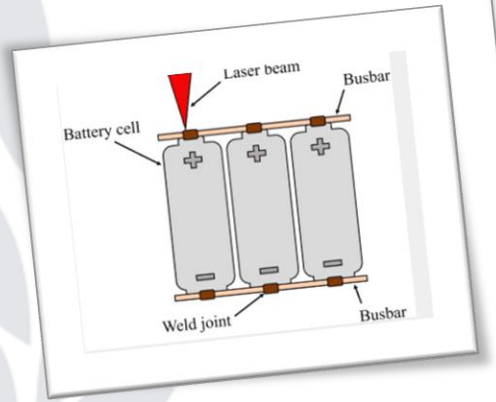
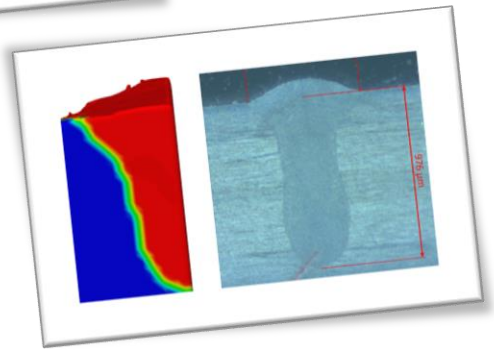
PRODUKTION2030

Virtual Manufacturing Processes (VMP)



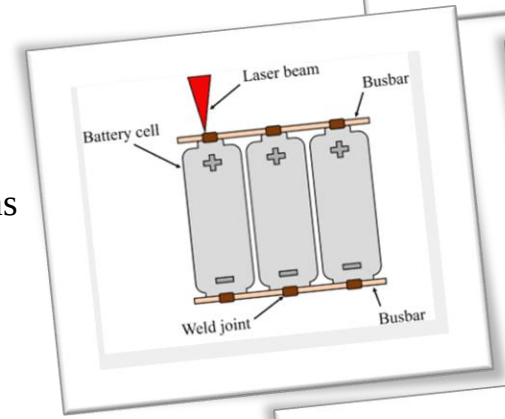
Demonstration of some laser welding applications

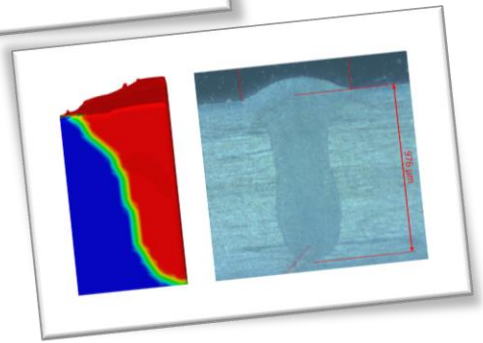




Agenda

- Our laser machine
- Materials and applications
- Ongoing research projects
- Laser welding of copper hairpins
- Laser welding of aluminium for battery applications
- Design of experiments and surface response methodology
- Laser welding simulations
  - Weld bead shape
  - Porosity formation
  - Copper hairpins
- Process simulations to structural simulations





Our laser machine

Machine

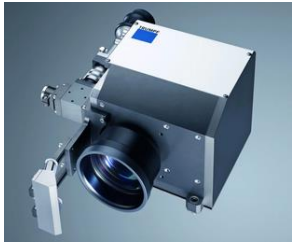
- 5-axis laser machine for welding and cutting

Laser source (TruDisk 6001)

- ”Solid-state” disc laser
- Wave length: 1030 nm (infrared)
- Adjustable laser power: 120 W – 6000 W
- Equipped with sensors for in-line quality assurance

Process adapters (laser heads)

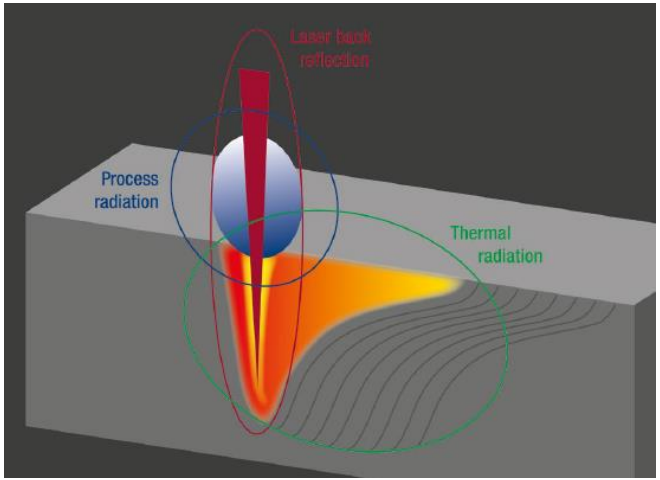
- Adapter for cutting
- Adapter for welding
- Programable Focusing Optics (PFO)

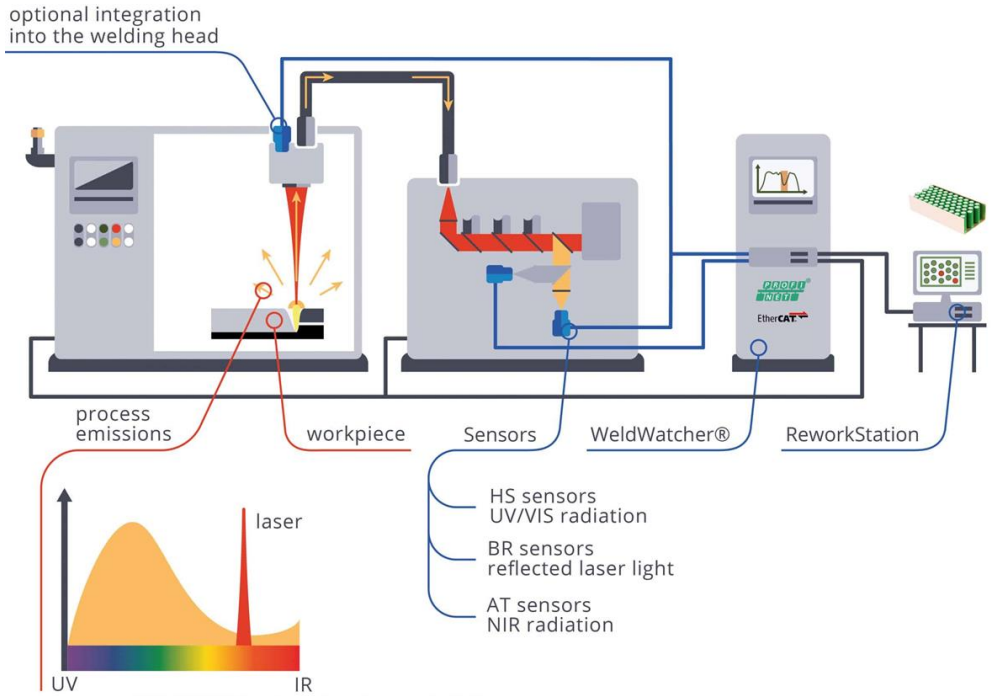


Images downloaded from: https://www.trumpf.com/en_US/products/machines-systems/laser-welding-systems-and-the-arc-welding-cell/trulaser-cell-3000/ [2023-05-01].

Laser Welding Photodiode-based In-Process Monitoring

4D Photonics





Materials and applications

Materials

- Copper
- Aluminum
- Steel, stainless steel
- Nickel-plated materials (copper and steel)

Applications

- Hairpin stators
- Batteries
- Hydraulic couplings
- Transmissions
- Sheet metal applications

Research projects

- UDI 3 (Vinnova)
  - LEAX
  - Aurobay
  - Volvo cars
  - Volvo GTO
- QWELD (Vinnova/ Produktion2030)
  - Aurobay
  - CEJN
  - Furhoffs
  - Koenigsegg
  - RISE
  - Volvo GTO
- LaserBATMAN (Vinnova/EU)
  - Aurobay
  - Volvo GTO
  - DTU
  - Resolvent

Laser welding of copper hairpins

- Investigate how different welding parameters affect:
  - Welding depth
  - Resulting temperature fields
  - Porosity in the joint
  - Mechanical strength
  - Electrical resistance

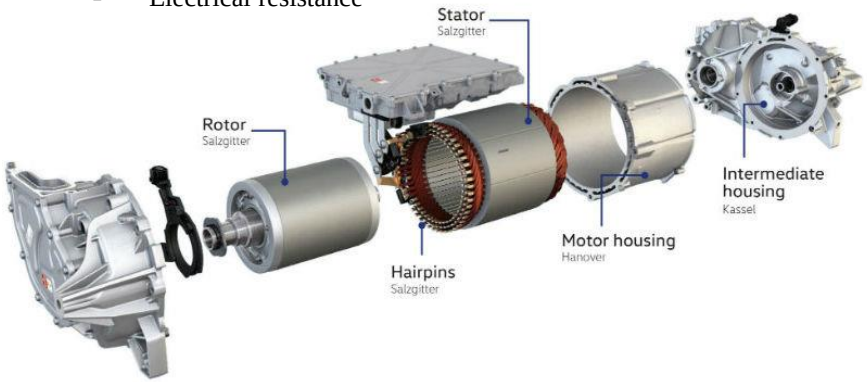
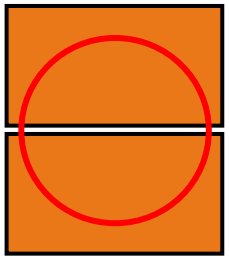
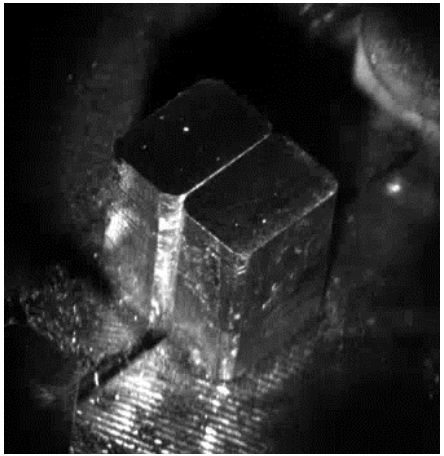


Figure downloaded from: https://www.automotiveev.com/volkswagen-group-components-to-supply-the-electric-drive-for-the-new-id-3/ [2023-04-25].

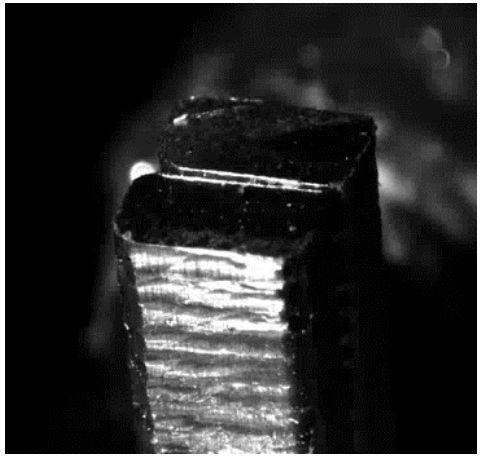
Laser welding of copper hairpins

Welding path:



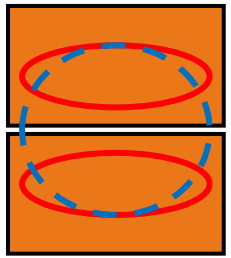


Power = 6000 W
Feed rate = 1000 mm/s
n = 16 rep
Circle



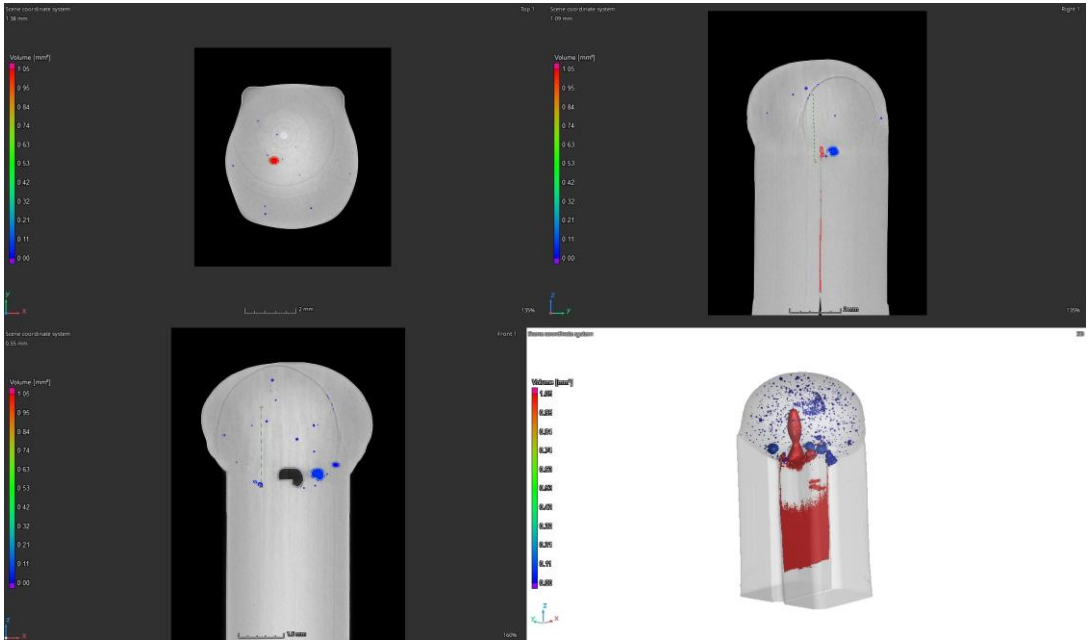
Power = 6000 W
Feed rate = 270 mm/s
n = 2.5; 1.25; 2 rep
BrightLine and 3 ellipses

Welding path:



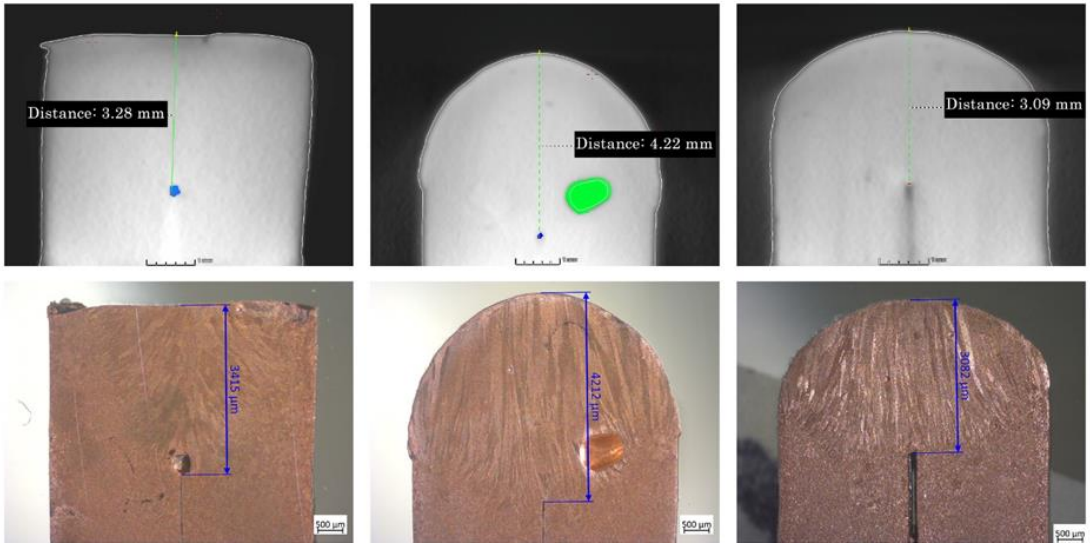
Laser welding of copper hairpins

- Computed Tomography (CT) scanning to analyse:
  - Porosities in the weld joint
  - Welding depth (depends on the application)



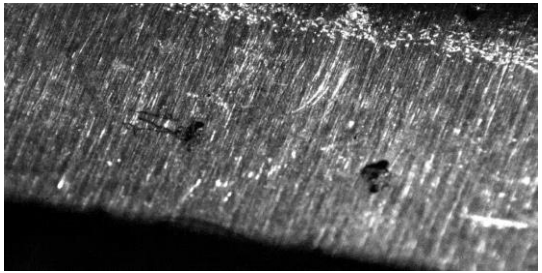
Laser welding of copper hairpins

- Welding depth from CT-scans
  - Measured distance from top of weld bead to the gap between pins
  - Welding depth can only be measured if there is a gap (CT-data only show differences in density)
- Welding depth from metallographic investigation
  - Cutting, grinding, polishing, etching, microscopy
  - More time consuming compared to CT-scanning

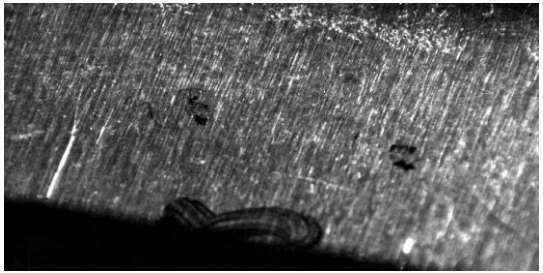


Laser welding of aluminium for battery applications

Power = 1000 W
Feed rate = 25mm/s
Energy = 40 J/mm (constant)



Power = 3000 W
Feed rate = 75mm/s
Energy = 40 J/mm (constant)



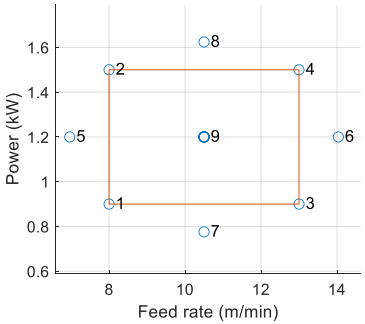
Power = 5000 W
Feed rate = 125mm/s
Energy = 40 J/mm (constant)

Design of Experiments (DoE) and Surface Response Methodology (SRM)

- Methodology to investigate the effect of different laser processing parameters on joint/weld characteristics:

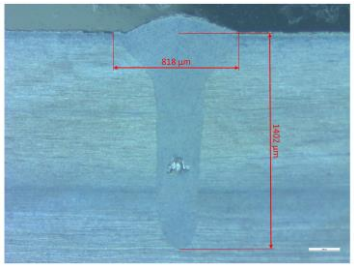
Design of experiments (DoE):

- eg. CCD, Box-Benhken



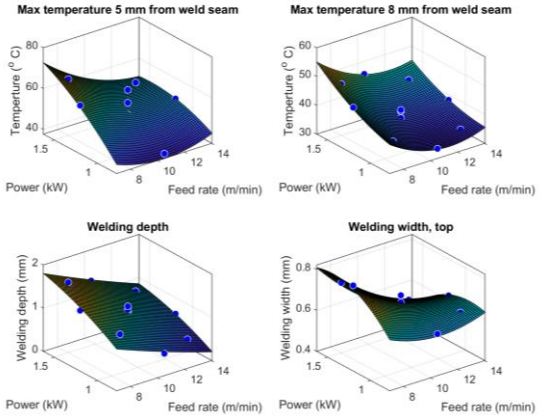
Experiments and data gathering:

- Laser welding experiments
- Temperature measurements
- Metallographic investigation
- CT-scanning



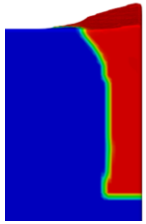
Data analysis:

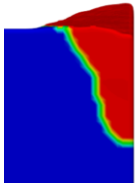
- Surface Response Methodology (SRM)
- eg. linear regression, neural networks

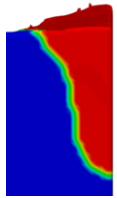


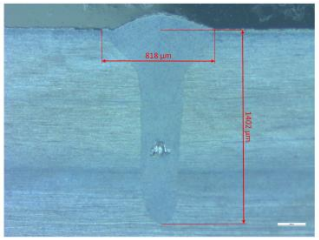
Laser welding simulations: Weld bead shape

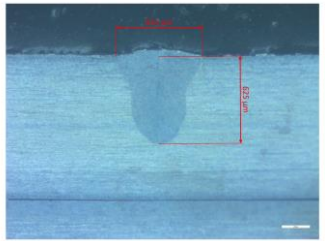
- CFD simulations of laser welding processes
  - Softwares: Flow 3D and Flow 3D Weld
  - Multi-physics, computational fluid dynamics (CFD) problem
  - Implementing the Volume of Fluid (VOF) method
- Used to predict:
  - Weld bead/keyhole shape
  - Melt pool flow and shape
  - Resulting temperature fields
  - Porosity formation

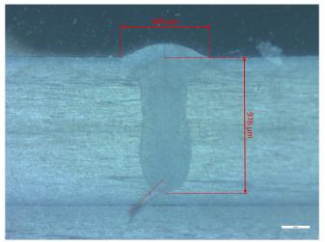










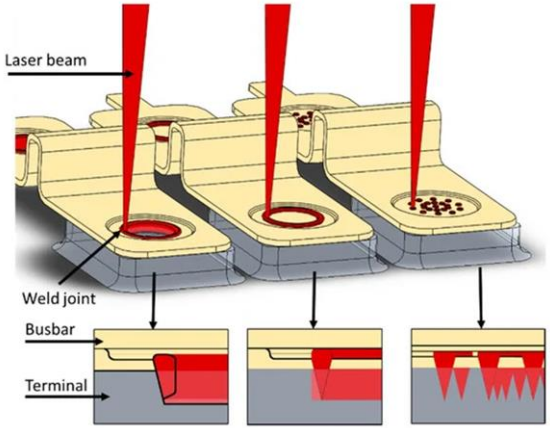


Stainless steel 1.4404:
P = 1200W
v = 7 m/min

P = 1200W
v = 14 m/min

P = 1200W
v = 10.5 m/min

Laser welding of battery busbars



Problem Area

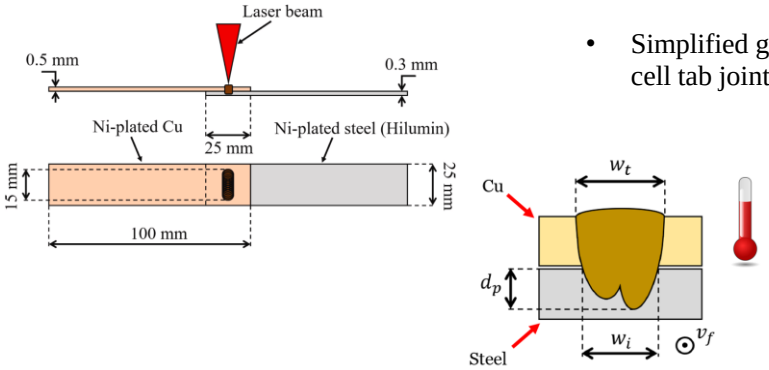
1) **Laser welding of battery**
   - Met and battery case (busbar)
   - Component
   - Welding's trials

2) **Weld quality examination**
   - Microstructural investigations
   - CT-scanning

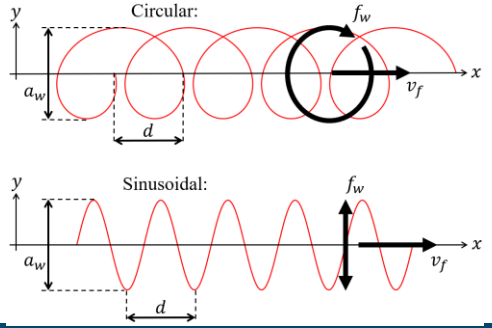
Laser welding of battery busbars

Published

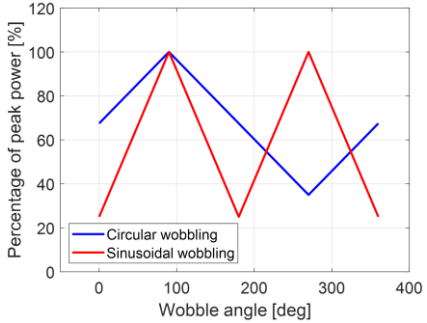
Optics & Laser Technology



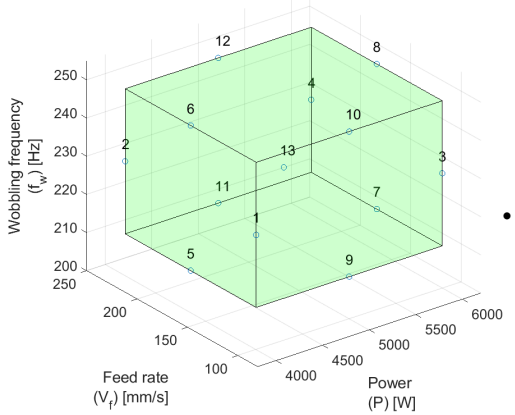
- Simplified geometry (busbar to cell tab joint Al EN AW 1050A)



- Circular and sinusoidal laser beam wobbling



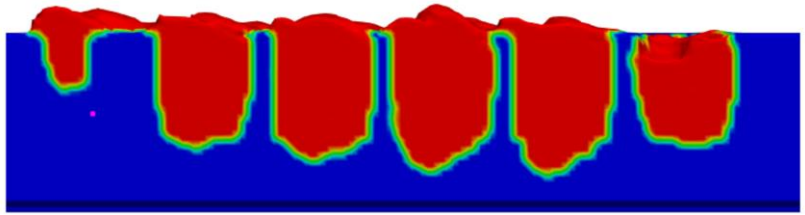
- Power modulation for a "smoother" energy input



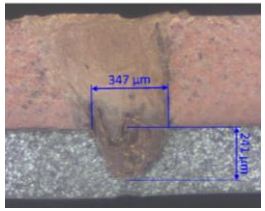
- Investigate the joint characteristics due to different parameter settings with the use of DoE

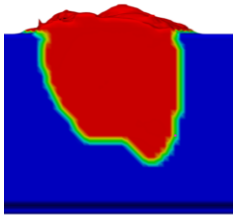
Laser welding of battery busbars

- CFD simulation of laser welding process
  - Softwares: Flow 3D and Flow 3D Weld
  - Multi-physics, computational fluid dynamics (CFD) problem
  - Implementing the Volume of Fluid (VOF) method
- Used to predict:
  - Weld bead/keyhole shape
  - Melt pool flow and shape
  - Resulting temperature fields
  - Porosity formation



Longitudinal direction (melt region)

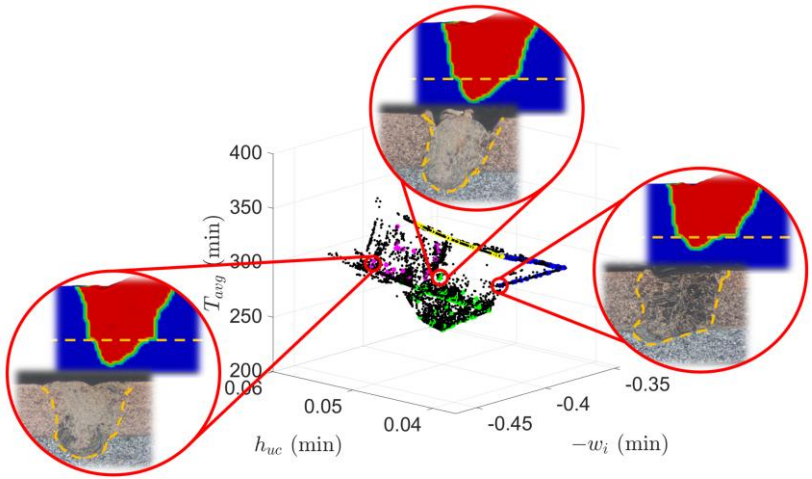




Longitudinal direction (micrograph)

Laser welding of battery busbars

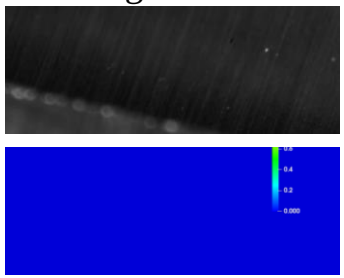
Meta model-based multi-objective optimization of laser welded dissimilar material joints for battery components

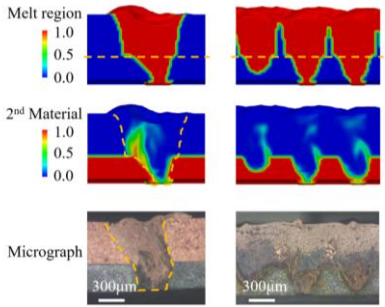


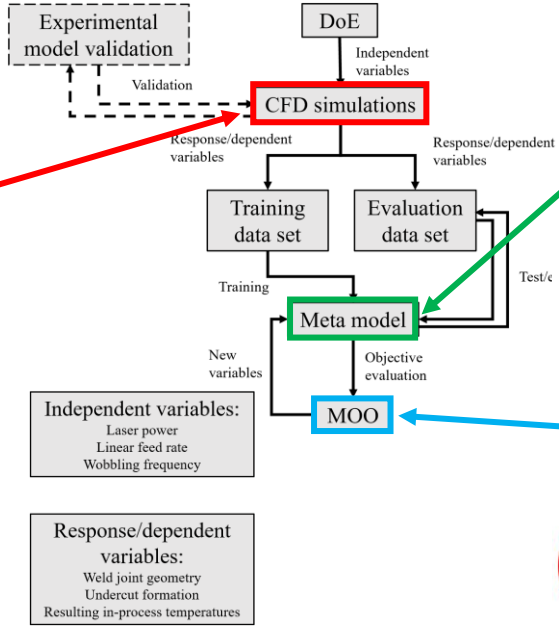
Ref. Andreas Andersson Lassila

Laser welding of battery busbars

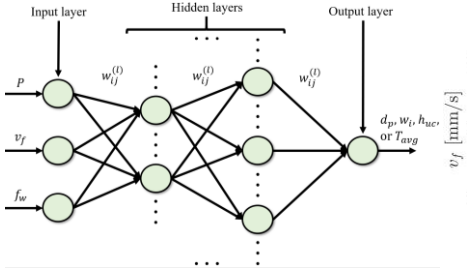
- CFD simulations for generation of training data

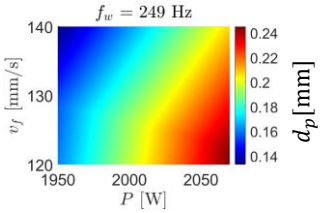




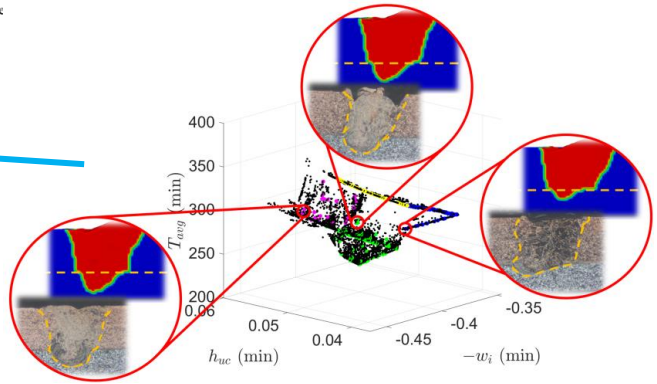


- ANN-based meta models for objective approximation

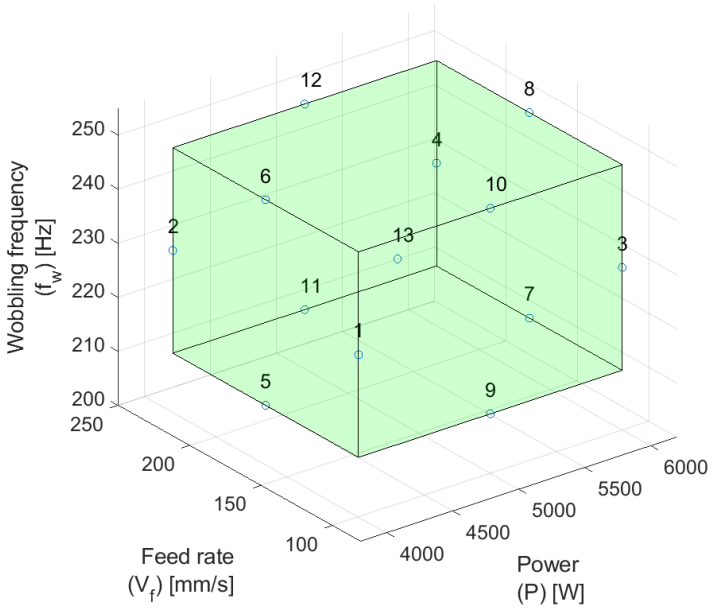




- MB-MOO using NSGA-II



Laser welding of battery busbars

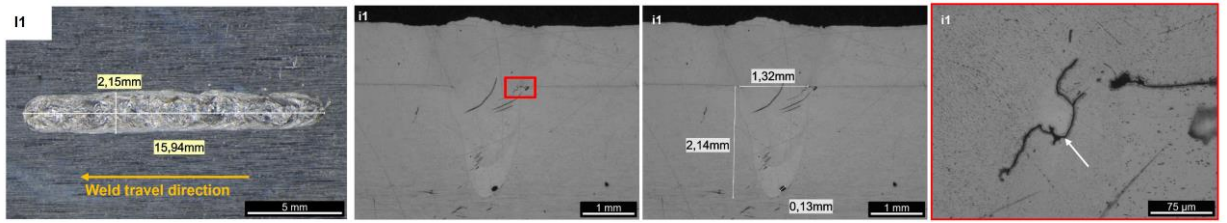


- Independent variables = Power (P), Feed rate (v_f) and Wobbling frequency (f_w)
- Dependent variables (quality measures) =
  - Weld seam appearance
  - In-process temperatures
  - Interface width
  - Welding depth

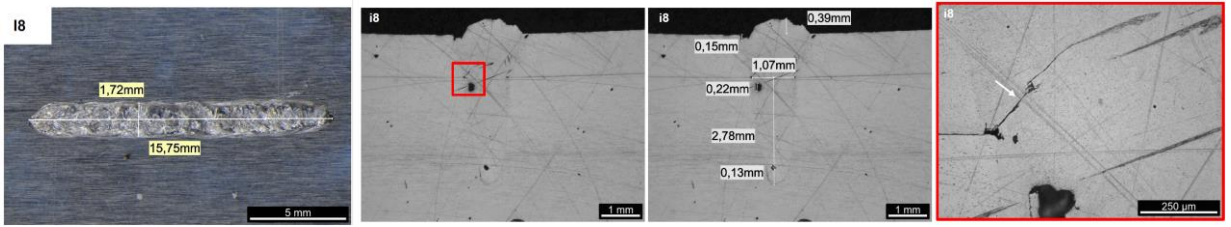
Laser welding of battery busbars

- Width/length of weld seam
- Welding depth
- Interface width
- Defects (porosity, hot cracks etc.)

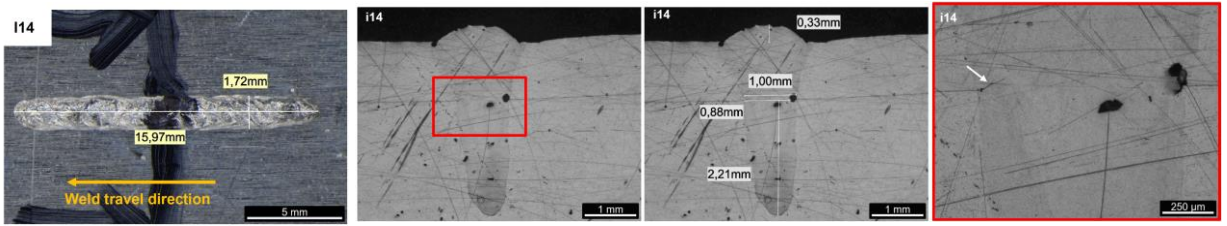
Sample 1



Sample 8

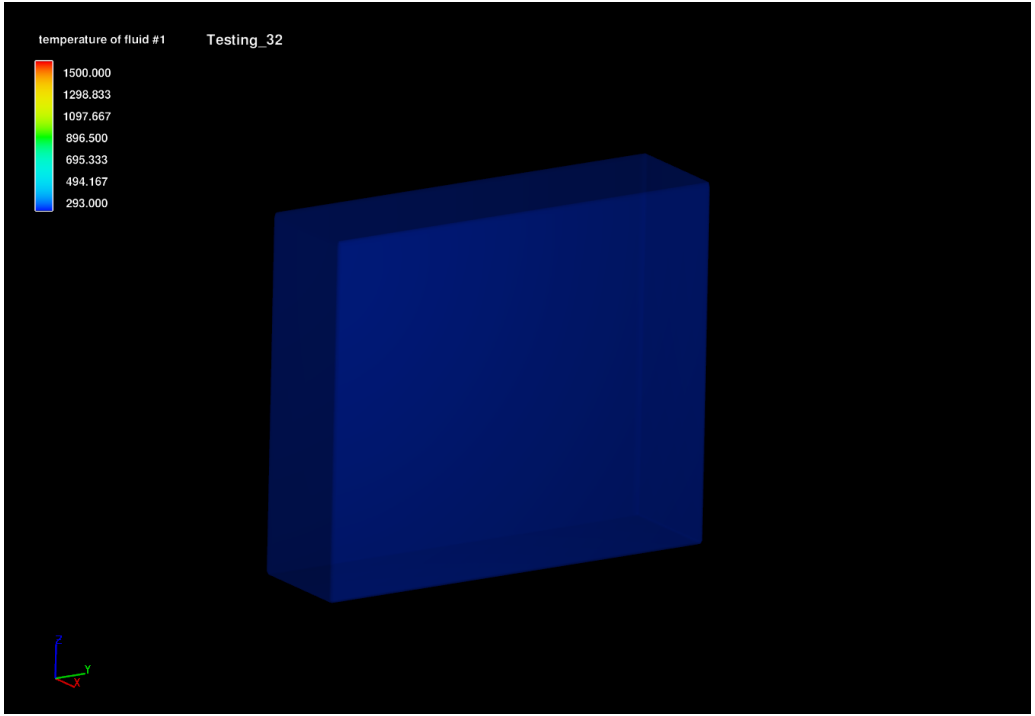


Sample 14



Laser welding simulations: Porosity formation

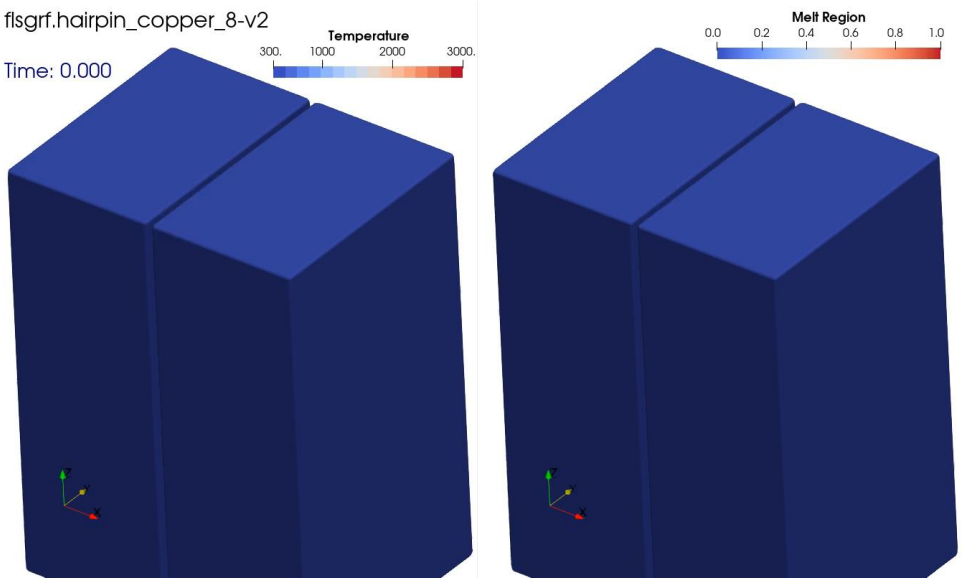
- CFD simulation of porosity formation in copper
  - Porosity formation in the bottom of the keyhole due to key collapse



Laser welding simulations: copper hairpins

- CFD simulation of laser welding of copper hairpins
  - Temperature and melt region

Process parameters:
P = 6000W
v = 1000mm/s
n = 20 rep
1x3mm ellipse



Process simulations to structural simulations

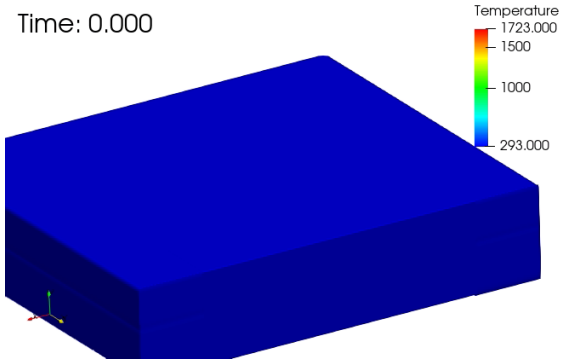
Process simulation:

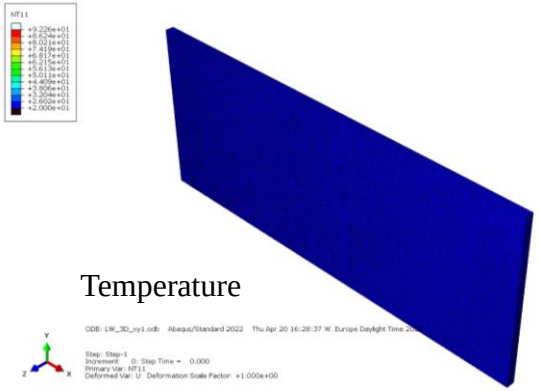
- Process zone modelled with CFD

Data flow

Structural simulation:

- Complete component modelled with FEM





Temperature

Von Mises stress

- Stainless steel EN 1.4404:
  - Power = 1200 w
  - Feed rate = 10.5 m/min

Thanks for your attention