Flexible use of laser beam technology for electromobility

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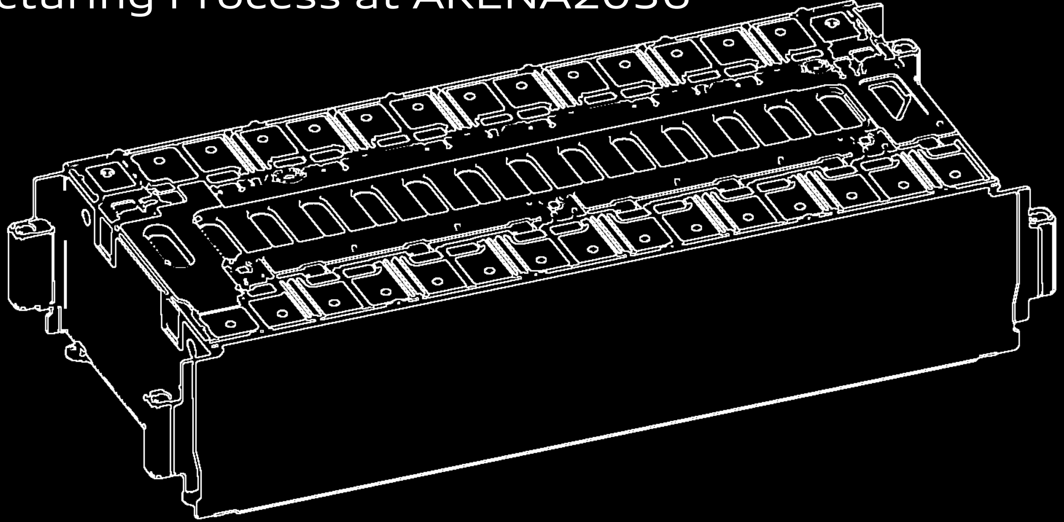
EPIC Meeting on Laser Applications along Battery Manufacturing Process at ARENA2036



Use of laser radiation in electromobility

Requirements

Material thickness	$50\ \mu\text{m} \le t \le 5\ \text{mm}$
Welding depth	$50\ \mu\text{m} \le s \le 10\ \text{mm}$
Weld seams per part	$1 \le a \le$ x00
Costs per part	> x00 €
Materials	aluminum, steel and copper

New **product requirements** (range, charging and performance) and a **strong increase in complexity** necessitate the use of highly flexible joining technologies

Selection of the
appropriate strategy and **system technology**
to fulfil the task

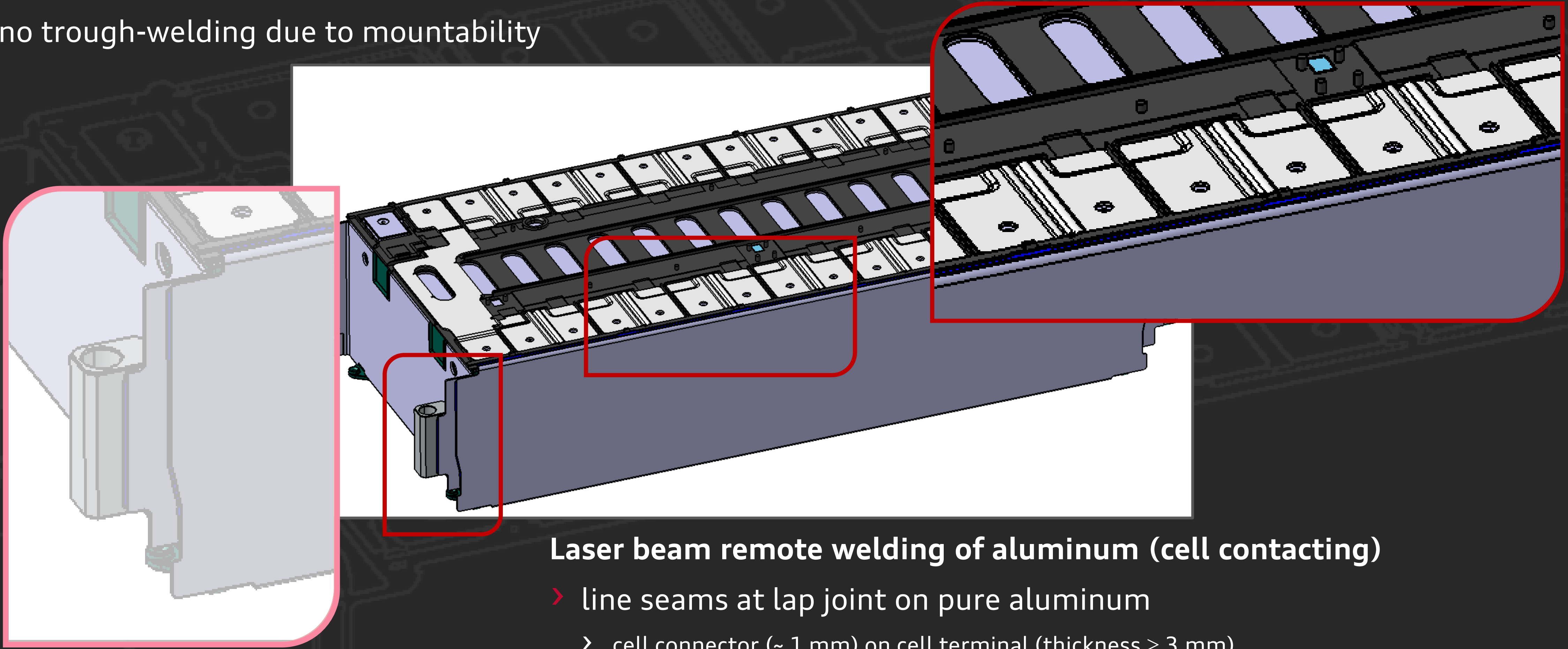
Requirements:
Connection area/ contact resistance
Connection quality/ strength
and
Process efficiency/ Productivity

» Laser beam technology offers a wide range of possible solutions for electromobility!

Challenge of prototyping: one equipment for different requirements

Laser beam remote welding of galvanized steel (HV-module housing)

- fillet welds at lap joint with different sheet thicknesses
  - side plate 0,8 mm on inner endplate 1,5 mm | inner endplate 1,5 mm on socket min. 2,5 mm
- no trough-welding due to mountability



Laser beam remote welding of aluminum (cell contacting)

- line seams at lap joint on pure aluminum
  - cell connector (~ 1 mm) on cell terminal (thickness ≥ 3 mm)
- no through weld to protect the battery cell with limit temperature of 85°C

Flexibility of the process as motivation

TruDisk

BrightLineWeld

PFO 3D SeamLineRemote

- material flexibility
- geometry flexibility
- adaptable
- sustainable

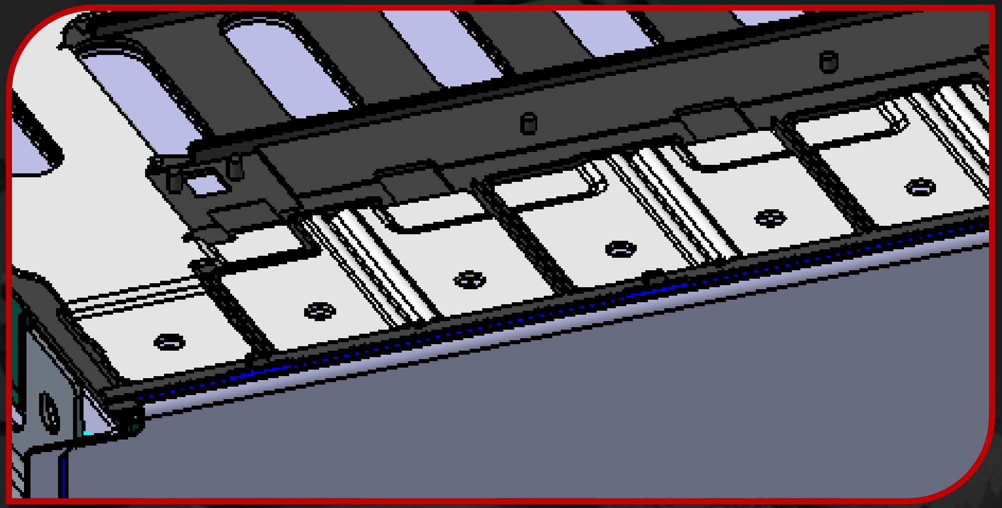
Laser beam remote welding of aluminum (cell contacting)

Strategy of process control

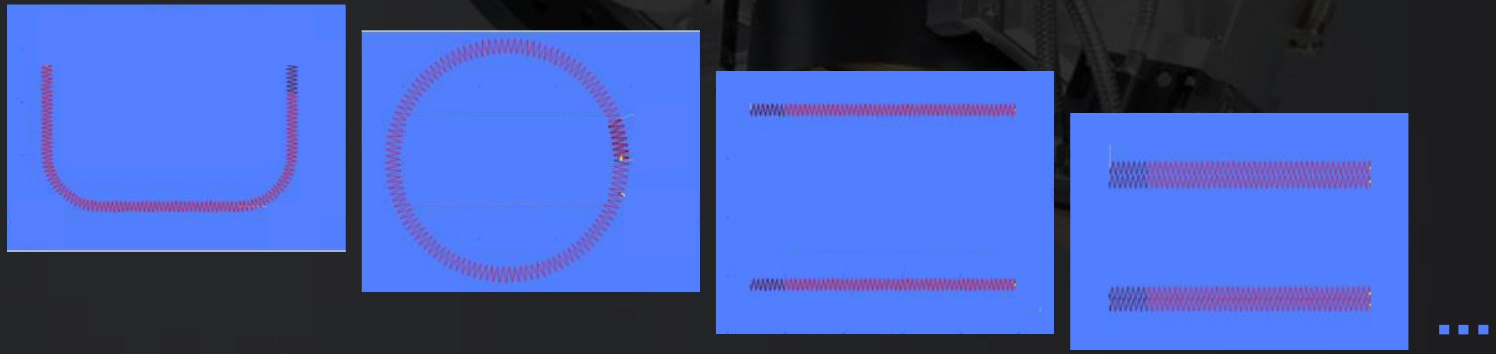
BrightLineWeld

Power distribution 100% in the core

- » small spot enables beam oscillation
- » adjustment of temperature field
- » reduction of seam imperfections



Seam geometry



» Synergies from car body construction can be used!

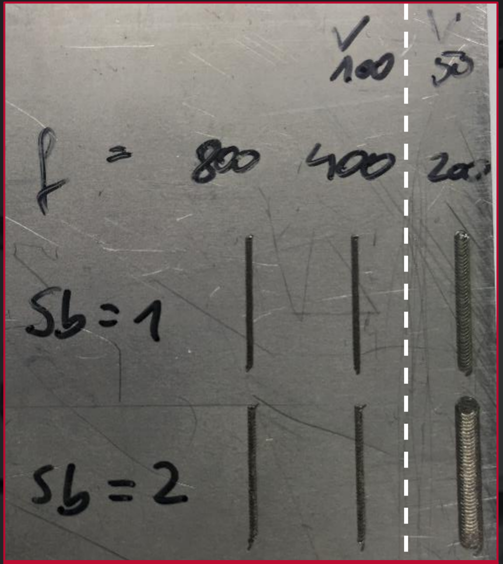
Laser beam remote welding of aluminum (cell contacting)

Strategy of process control

Beam oscillation

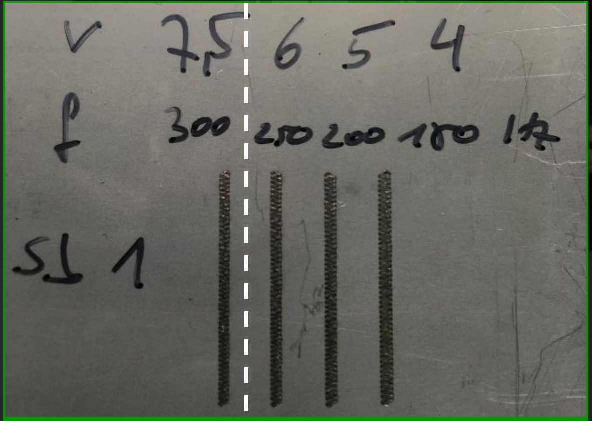
Key factors

- path accuracy up to a frequency f ≤ 250 Hz reached (feed rate ∝ frequency)
- oscillation pattern
  - circular: beam velocity at surface almost constant
    BUT: V-shaped seam cross-section with insufficient connection width
  - lateral: reduced beam velocity in the reversal points corresponds to feed rate
    THUS: increased heat input with U-shaped seam cross-section a sufficient connection width

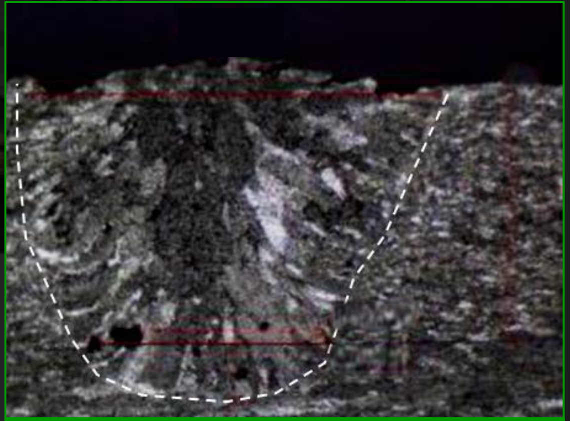


circular oscillation

circular oscillation



lateral oscillation



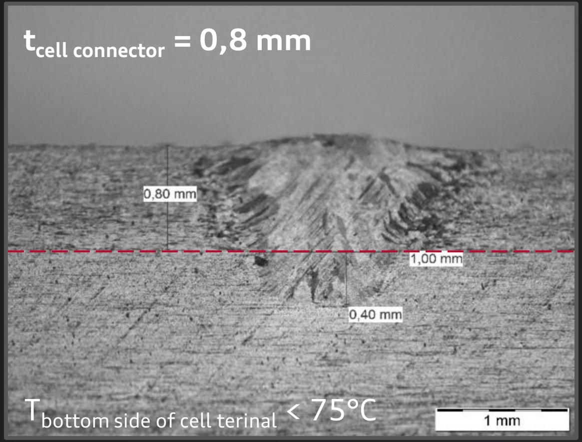
lateral oscillation

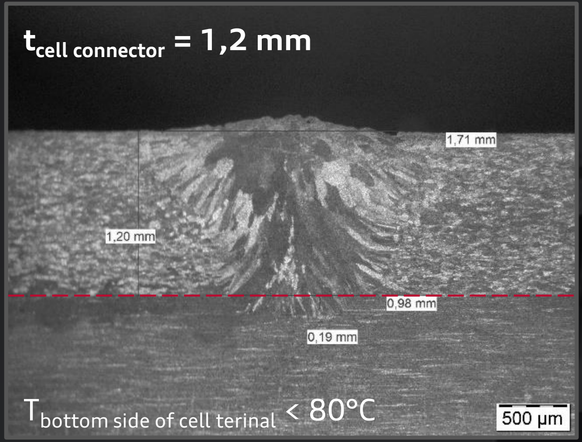
Laser beam remote welding of aluminum (cell contacting)

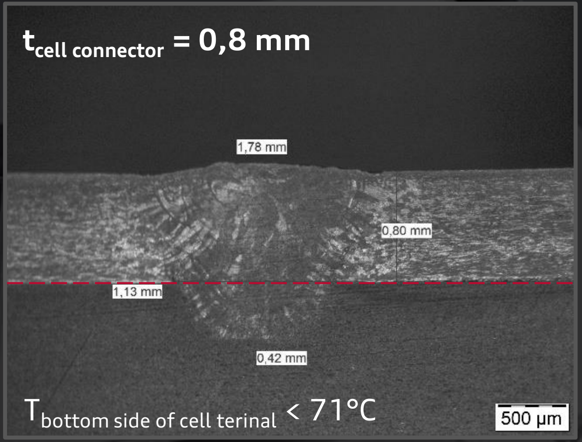
Presentation of results

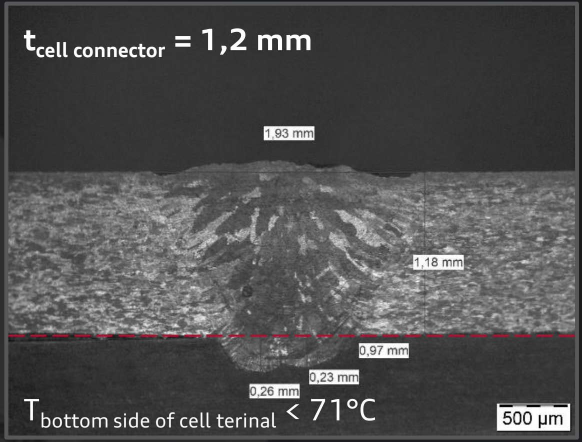
Thickness of cell terminal t = 3 mm

Thickness of cell terminal t >3 mm









Status Quo:

- necessary connection width achieved in all constellations ✓
- ideal seam geometry determined ✓
- strength of all connections guaranteed ✓
- **limit temperature at the bottom side of cell terminal is not exceeded** ✓
- **contact resistance $R < 15\ \mu\Omega$** ✓

Cell terminal: Al

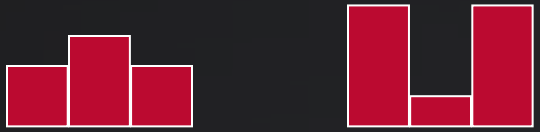
» Contact resistance corresponds to the specific value of base material (performance increase of the entire battery)

Laser beam remote welding of galvanized steel (HV-module housing)

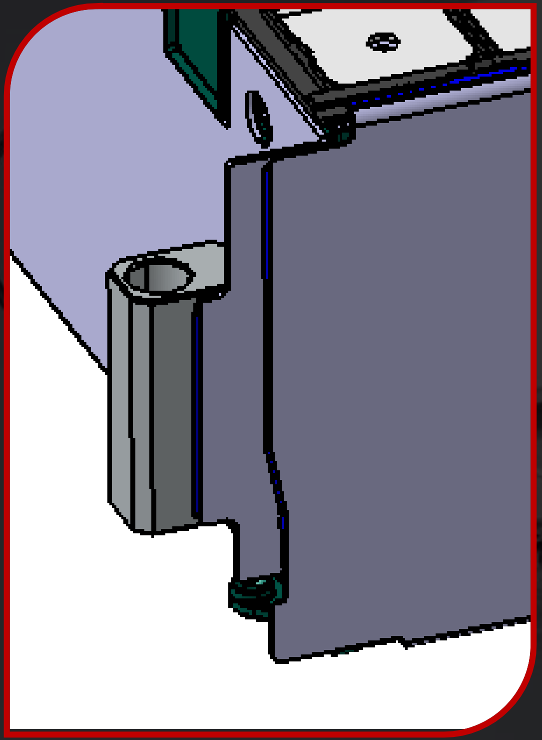
Strategy of process control

BrightLineWeld

Adjusted power distribution

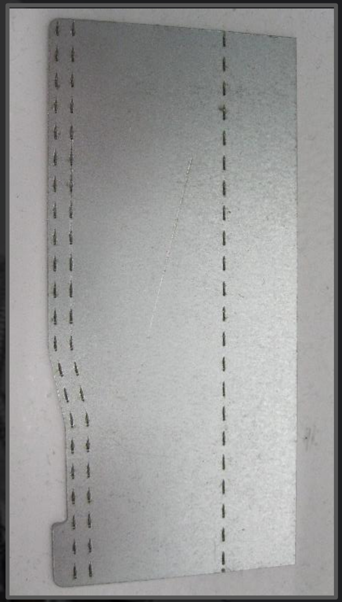


- » edge tracking by means of laser triangulation
- » adjusted connection cross-section using power distribution



Laser dimpling

Power distribution 100% in the core



- » laser dimpling for zinc degassing

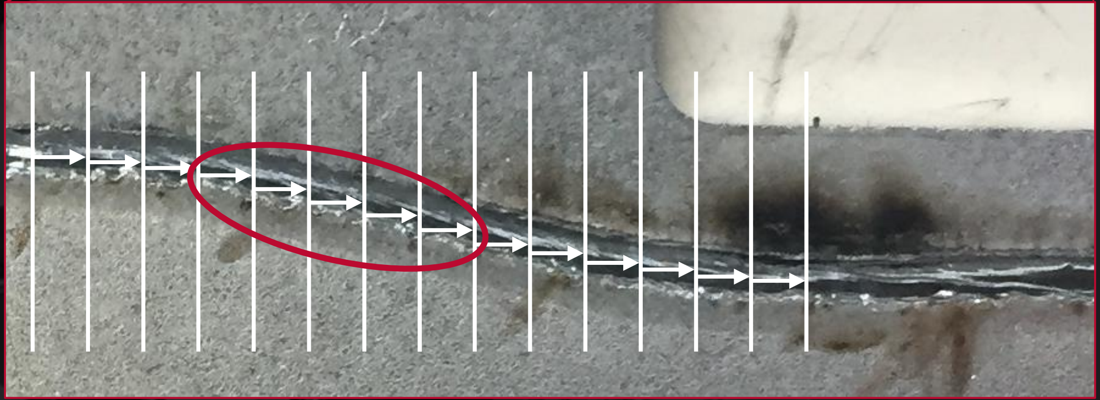
» Use of laser beam on battery module housing due to high strength and minimal package requirements!

Laser beam remote welding of galvanized steel (HV-module housing)

Presentation of results: side plate 0,8 mm on inner endplate 1,5 mm

direction of travel 1: offset 0,2 mm

direction of travel 2: offset 0,3 mm

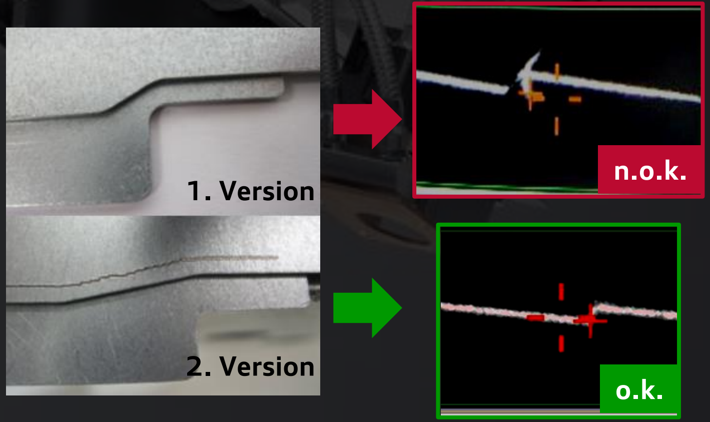


Influence of direction of travel on lateral offset

- direction of travel 1: lateral offset = 0,2 mm
- direction of travel 2: lateral offset = 0,3 mm
  - Avoidance of trough-welding due to path correction (trigger distance = 1 mm)

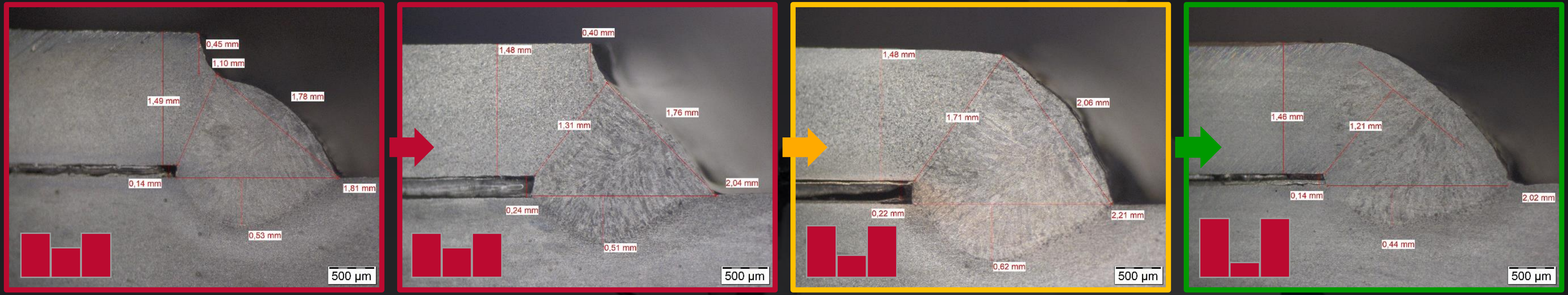
Influence of direction of travel on edge tracking

- direction of travel 1: edge tracking o.k.
- direction of travel 2: Scattering of triangulation lines at cutting
  - geometry adjustment of side plate



Laser beam remote welding of galvanized steel (HV-module housing)

Presentation of results : inner end plate 1,5 mm on socket



Essential development steps

- adjustment of power distribution in BrightLineWeld to increase the connection width » *decrease in notches*
- increasing the lateral angle and reducing the feed rate to improve lateral bonding

» Flexibility of the tool to ensure high quality joints even in steel!

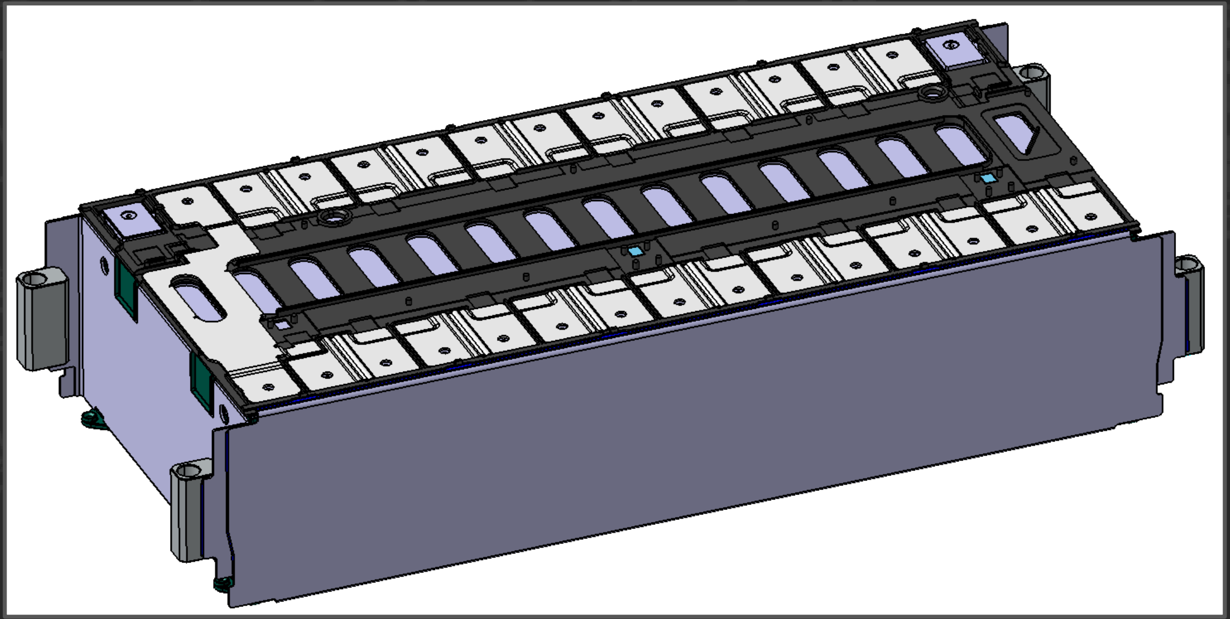
Use of laser radiation in electromobility

Interim conclusion

Plant technology designed

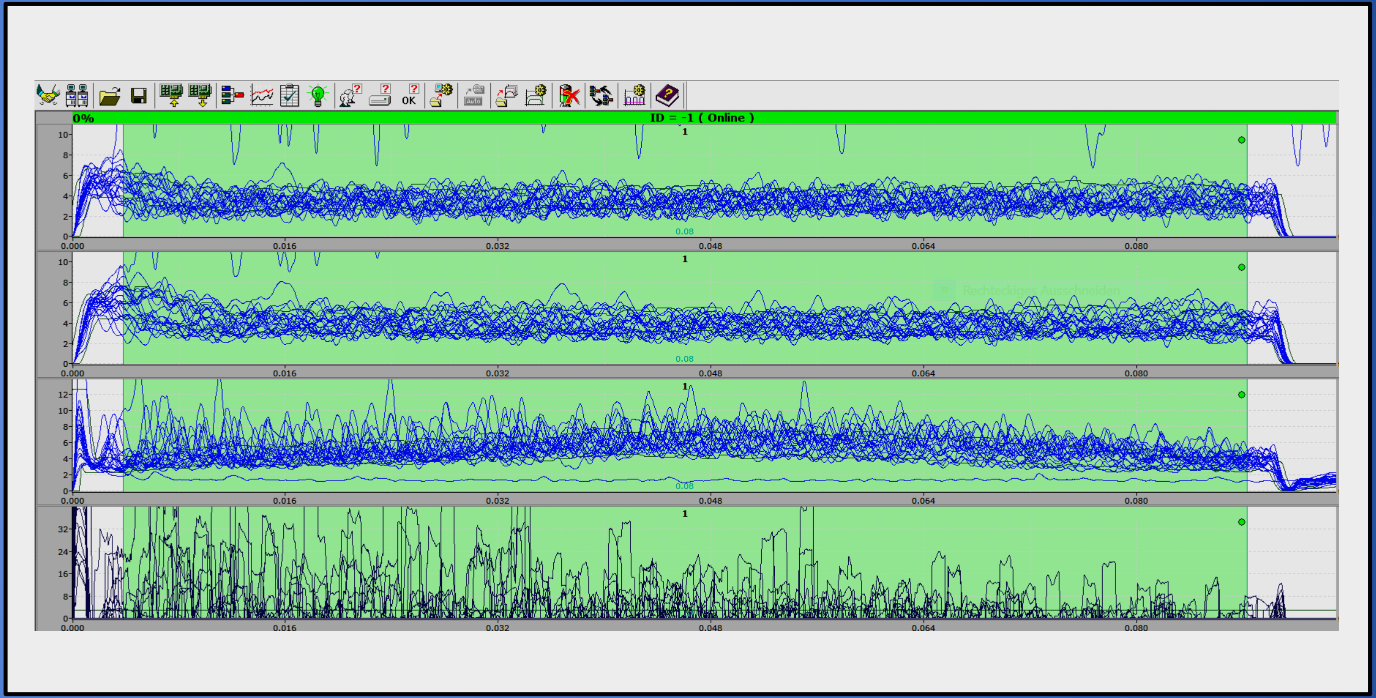
Parameters developed

Clamping concept developed



» ONE flexible equipment for different requirements to increase sustainability

Holistic system approach to ensure productivity

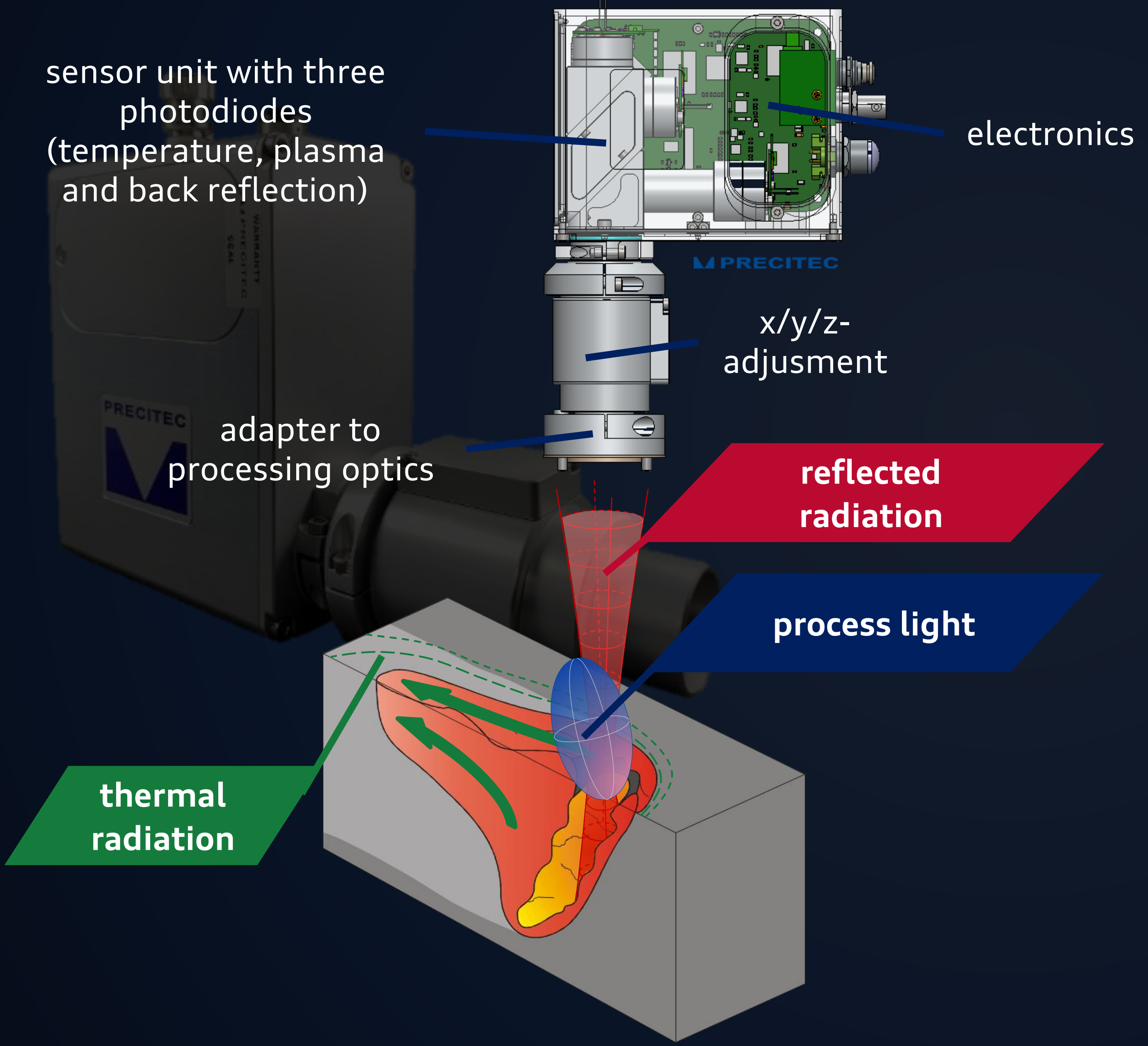


Laser Welding Monitor 4.0

Use of process emissions for quality assurance in laser beam welding of cell connectors

Adaption LWM-sensor (LaserWeldingMonitor) to processing optics

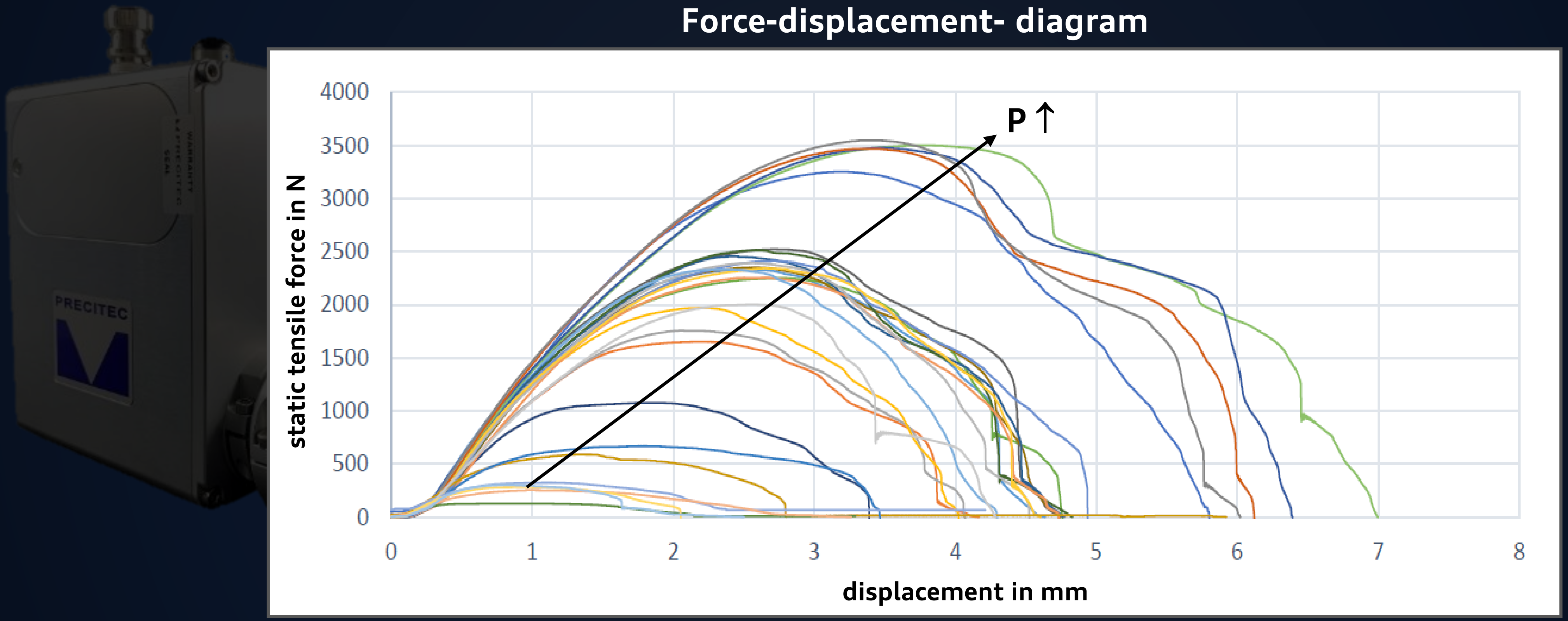
Measuring principle and mode of operation



Online process control guaranteed

- recording of process emissions with photodiodes in three wavelength ranges
- non-destructive quality recording of the joint quality in real time
- reliable defect detection with 100% online quality assurance
- 24/7 transparency and traceability

Influence of laser power on static tensile force

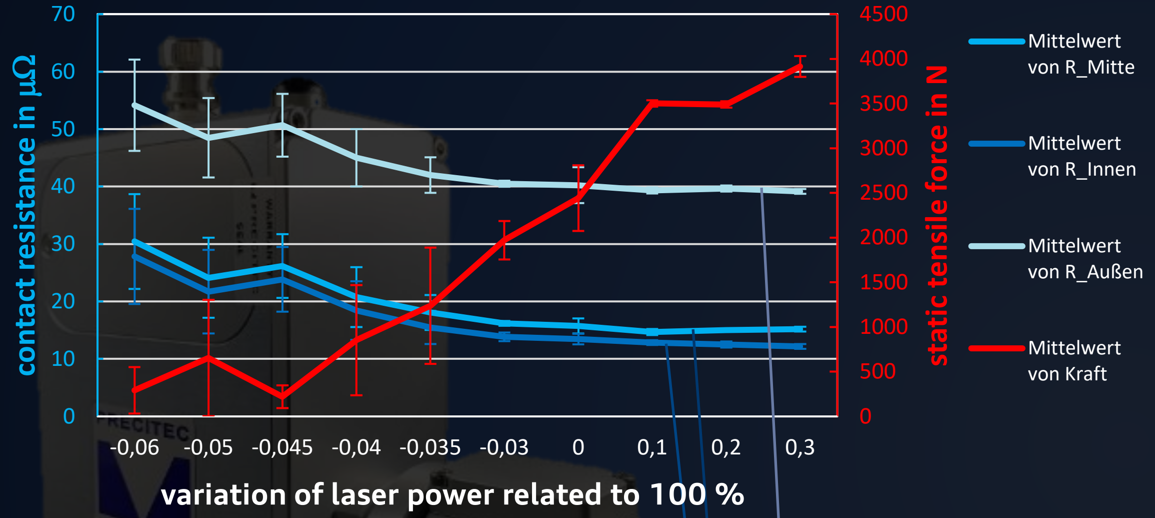

Force-displacement- diagram

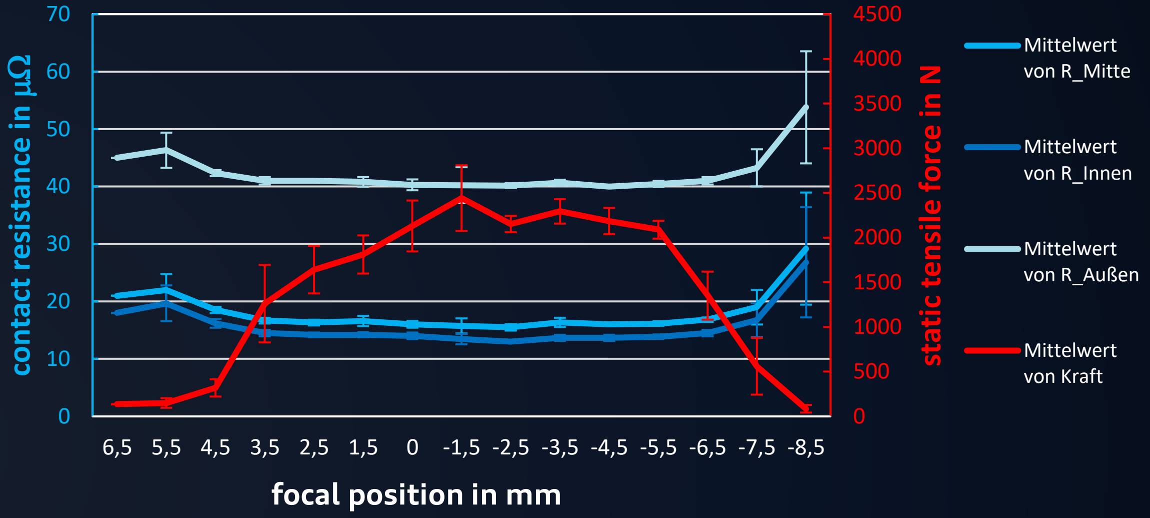
Increase of laser power leads to

- an increase of welding depth and joint width in the connection plane
- and thus, an increase in static tensile force

Measured value display

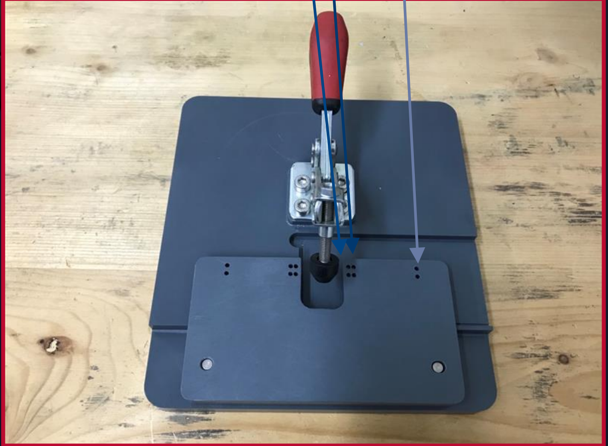
Influence of laser power/ focal position on contact resistance/ static tensile force





Chauvin Arnoux 6240

measuring device



clamping for measurement

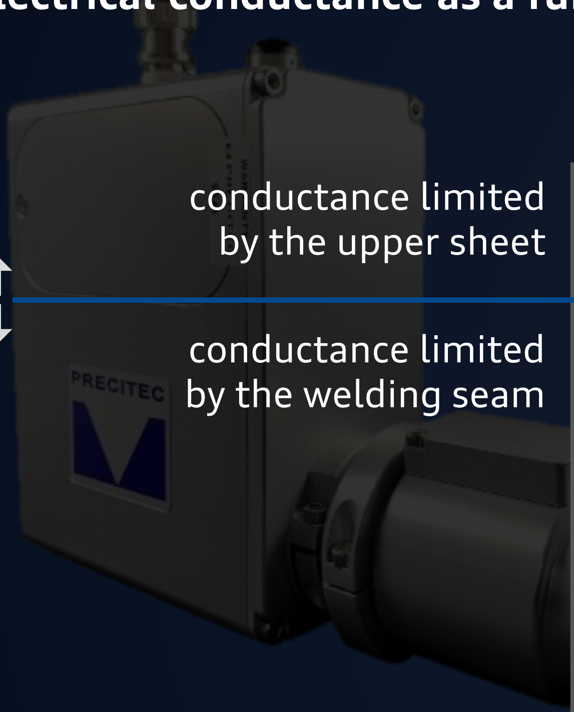
- Increase in static tensile force in N
  - increasing laser power
  - focal position slightly below workpiece surface

- and thus, a decrease in contact resistance in µΩ as a function of the distance between the measuring tips (the greater the distance the greater the contact resistance)

Measured value display

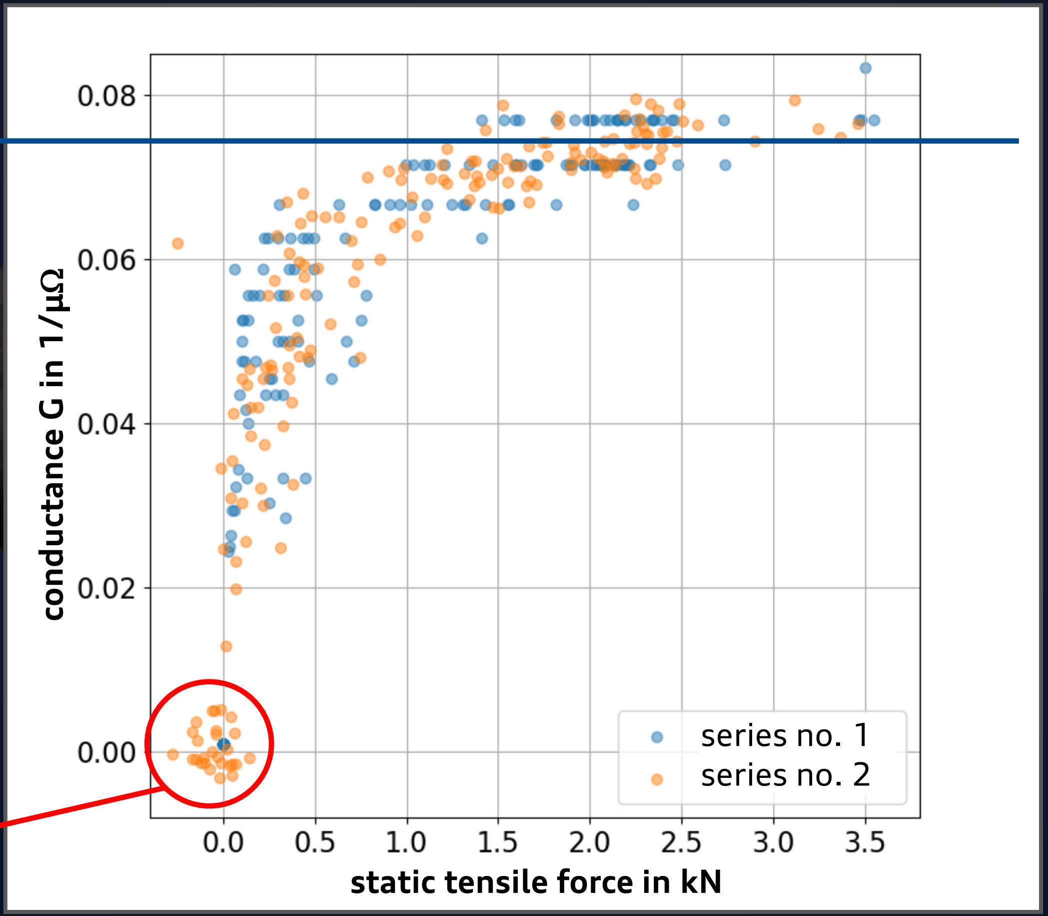
Influence of laser power/ focal position on contact resistance/ static tensile force

Electrical conductance as a function of the static tensile force



conductance limited by the upper sheet

conductance limited by the welding seam

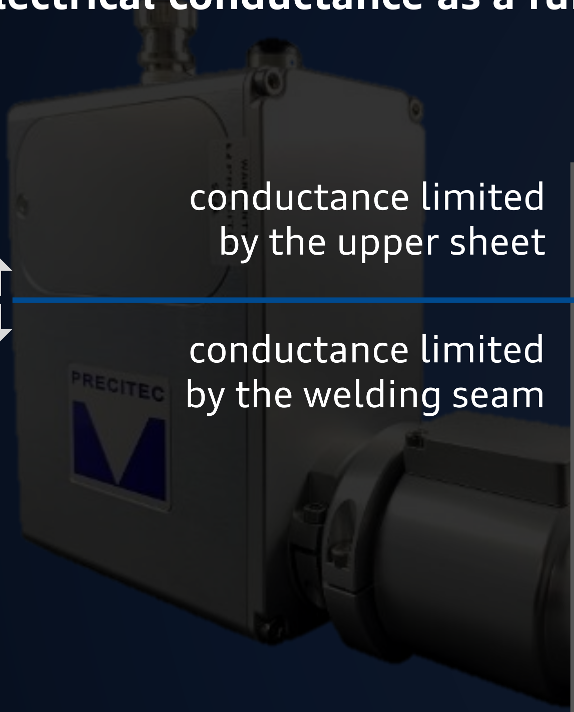


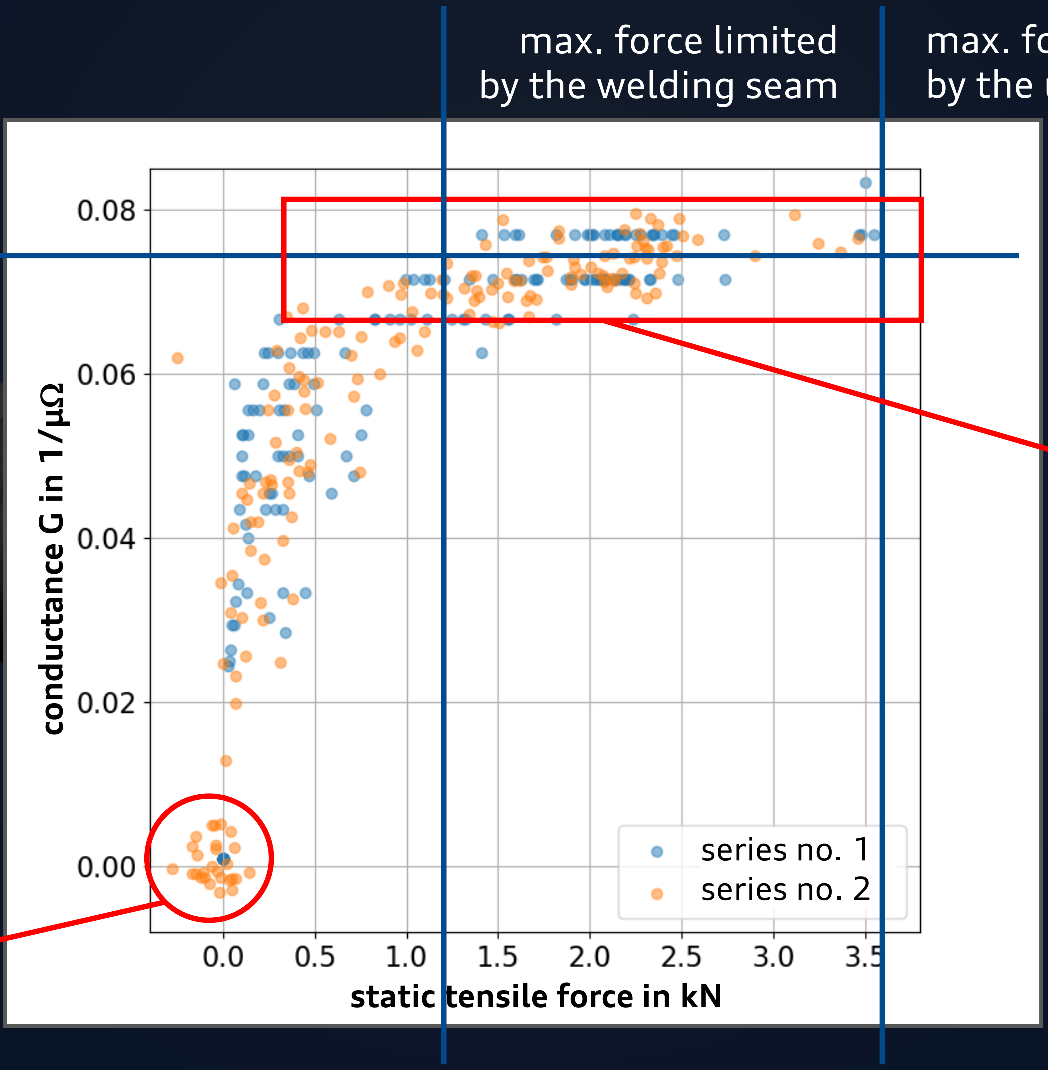
F = 0 N → R ∞

Measured value display

Influence of laser power/ focal position on contact resistance/ static tensile force

Electrical conductance as a function of the static tensile force





max. force limited
by the welding seam

max. force limited
by the upper sheet

conductance limited
by the upper sheet

conductance limited
by the welding seam

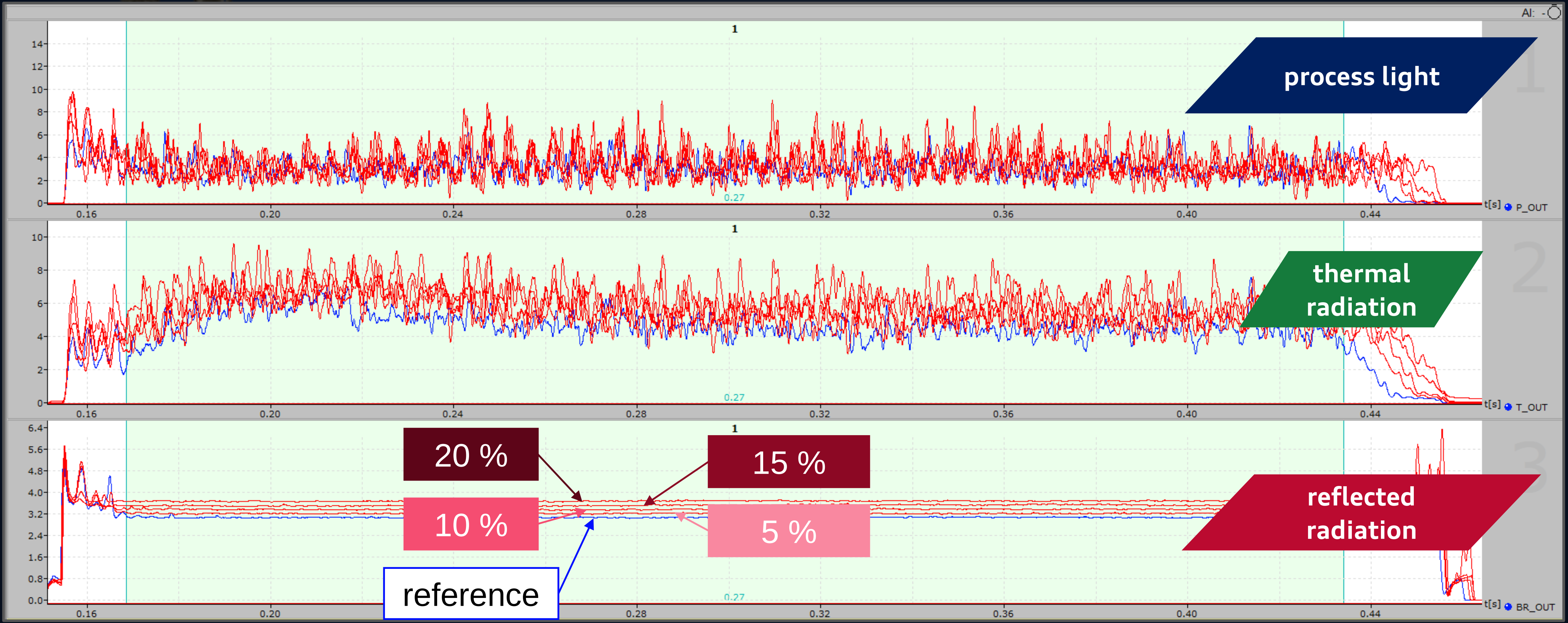
max. conductance is reached
before the max. static tensile force

F = 0 N → R ∞

Measured value display

Influence of laser power

Influence of laser power on process emissions with photodiodes in three wavelength ranges



process light

thermal radiation

reflected radiation

20 %

15 %

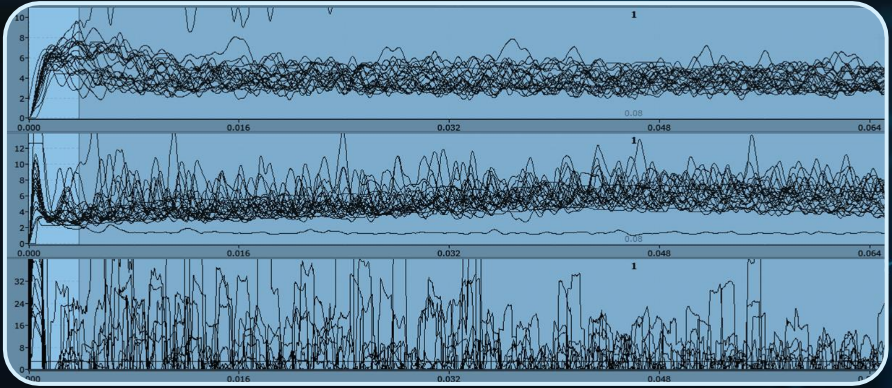
10 %

5 %

reference

Working hypothesis

Use of LWM signals for extraction of absolute physical values

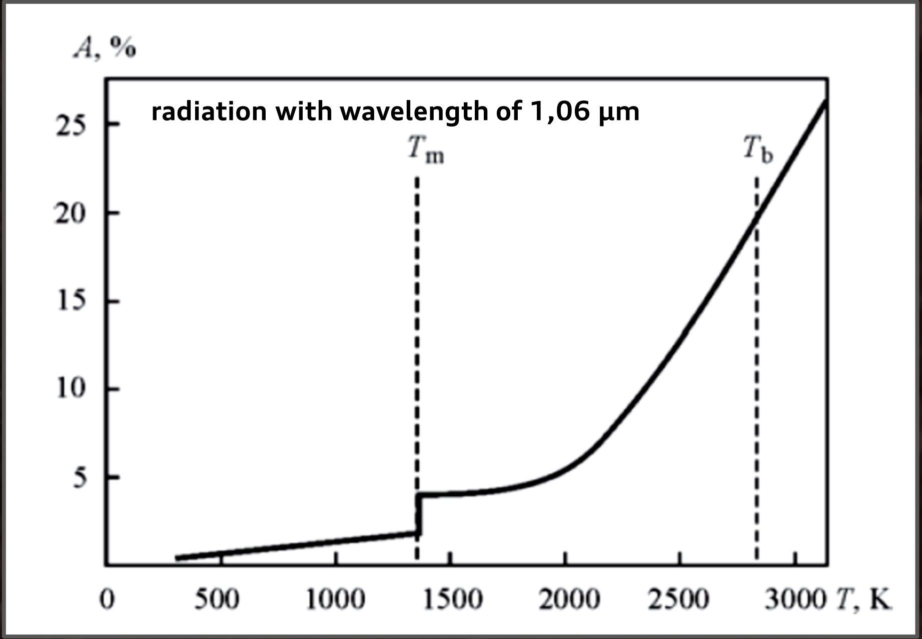


Contribution LASER for a flexible production line for tomorrow's production

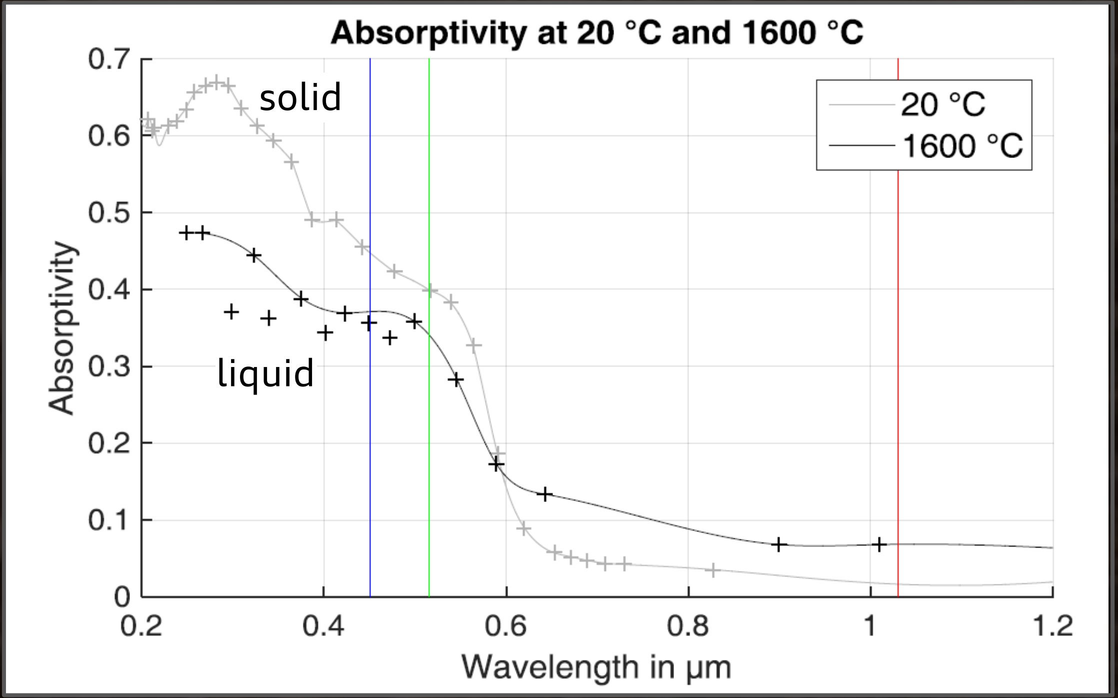
Fundamentals: Absorption of cold (solid) and hot (liquid) copper

Near infrared (IR): 1 µm

- Copper absorbs about 2% at room temperature
- Increase of absorptivity with increasing temperature (2% @ RT / 5% @ T_m / 20% @ T_b)



source: V. Khaskin et al: Effect of laser radiation absorption on efficiency of laser welding of copper and its alloys, The Paton Welding Journal, No. 11, 2016, p. 31-35.



source: S. Kohl; Institute of Photonic Technologies, Erlangen

Visible wavelengths: 450 nm (blue) and 515 nm (green)

- Copper absorbs about 45% (blue) and 40% (green) at room temperature
- Reduced absorptivity at liquid copper with low absolute absorption difference

Technology equipment and experimental setup

Sorted by ascending wavelength

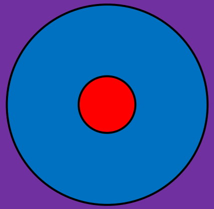
LDMblue 1.500-60
P_{max} = 1500 W

d_{fiber} = 600 µm
$f_{collimation}$ = 112 mm
f_{focus} = 112 mm
d_{focus} = 600 µm

TruDisk green
P_{max} = 3000 W

d_{fiber} = 200 µm
$f_{collimation}$ = 150 mm
f_{focus} = 255 mm
d_{focus} = 340 µm

Hybrid
superposition of LDMblue 1.500-60 and LDF 10.000-6



LDF 10.000-6
P_{max} = 10.000 W

d_{fiber} = 300 µm
$f_{collimation}$ = 200 mm
f_{focus} = 112 mm
d_{focus} = 170 µm

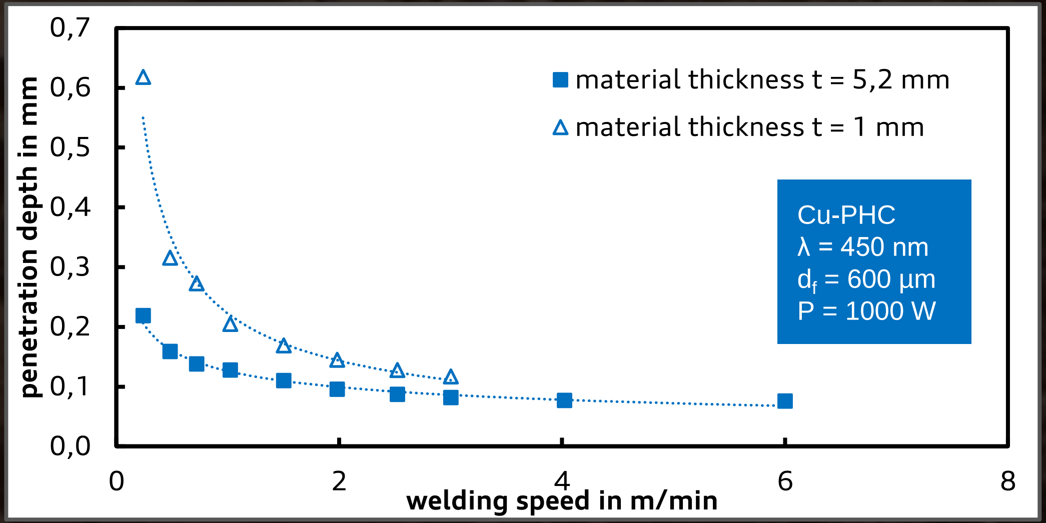
source: TRUMPF GmbH + Co. KG, Laserline GmbH

Technology equipment and experimental setup

Influencing factors and test parameters

Material thickness has significant influence on welding results

- Heat accumulation effect caused by thermal conductivity
- All experiments were performed with thick copper plates to ensure optimal heat transport

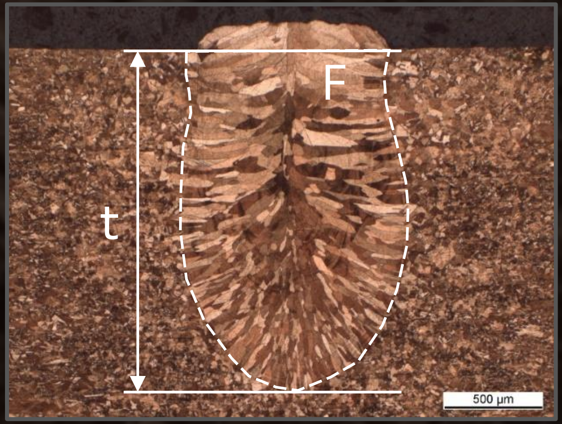


Varied process parameters to determine the process efficiency

- Wavelength λ = 450nm ; λ = 515 nm ; λ = 1080nm as well as the combination of λ = 450nm and λ = 1080nm (Hybrid)
- Laser power and welding speed depending on source
- Copper alloy Cu-PHC

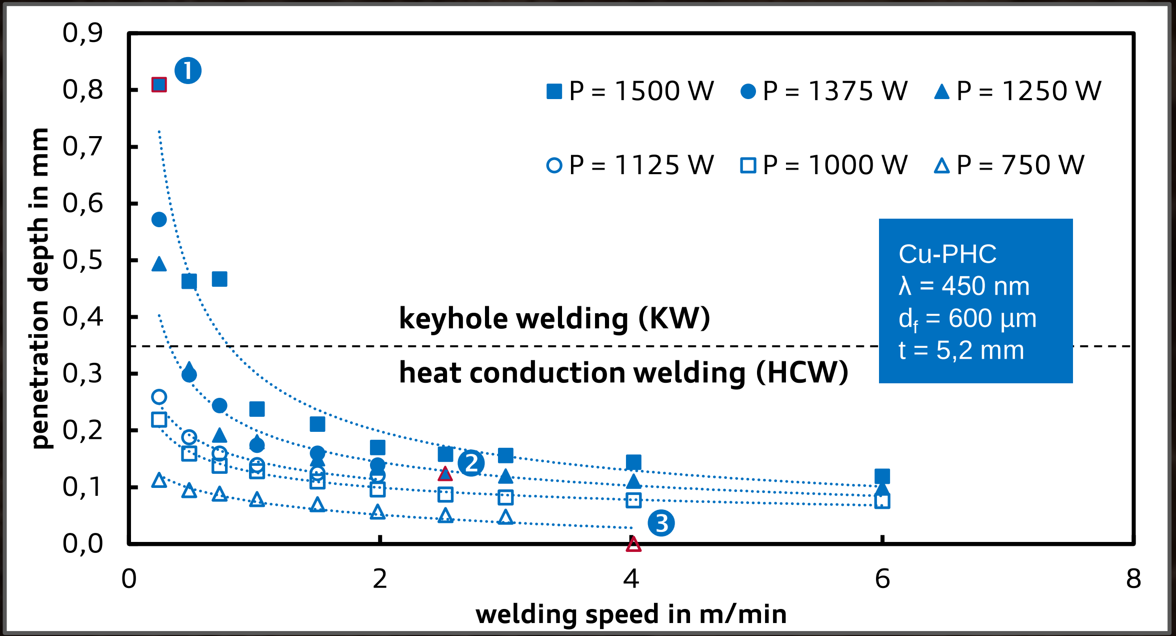
Determination of measures for metallographic investigations

- F: weld seam area in mm²
- t: penetration depth in mm

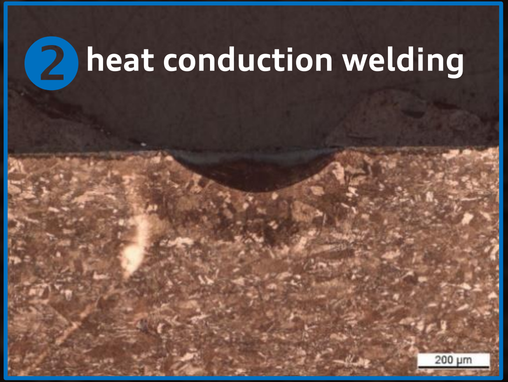


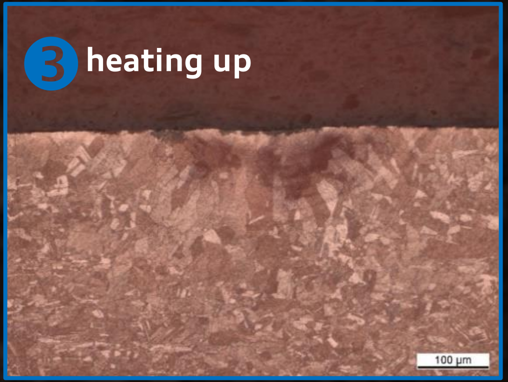
Laser beam welding of copper alloys for e-mobility

Welding with visible wavelengths with respect to the welding depth




① keyhole welding


② heat conduction welding

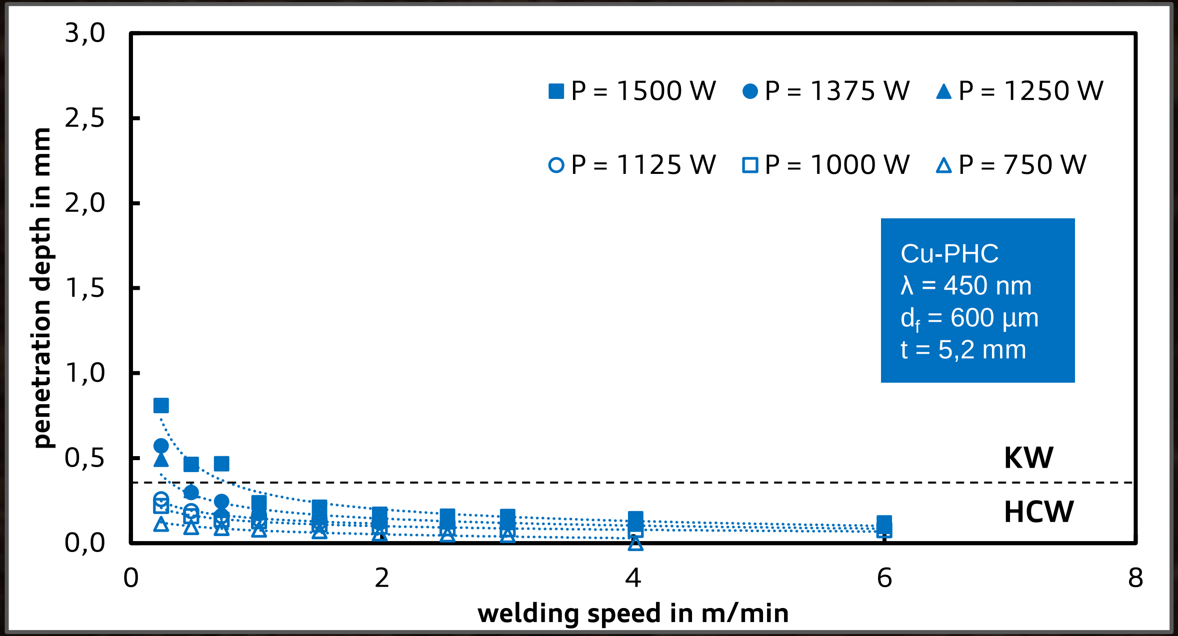

③ heating up

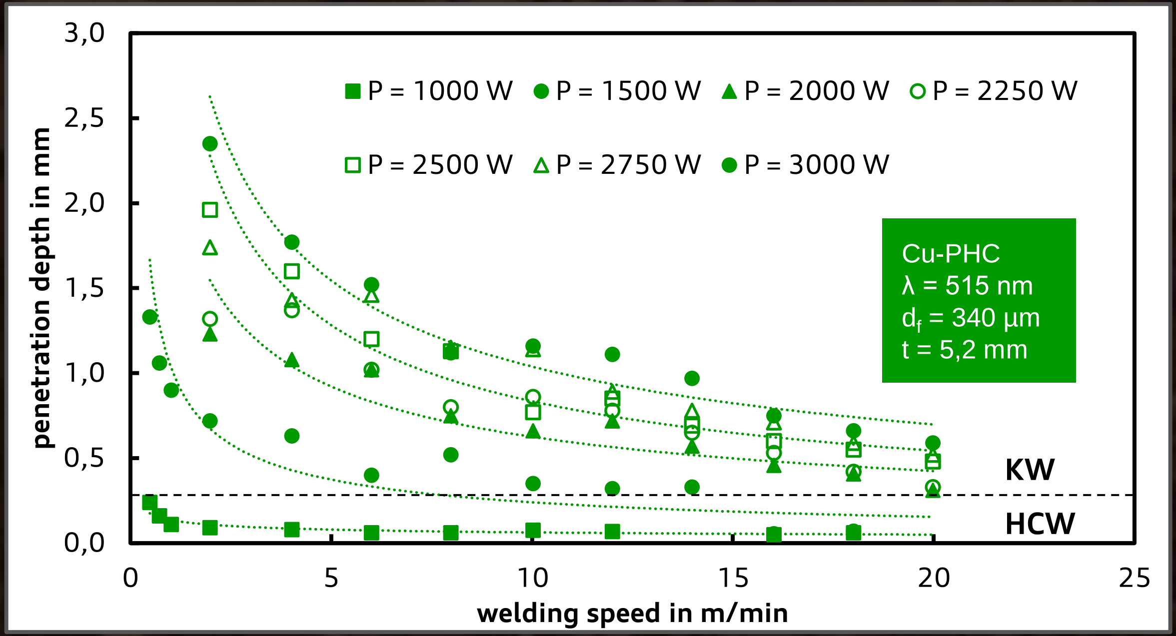
Welding with wavelength λ = 450nm

- Achievable penetration depth in investigated parameter field very low
- Threshold for keyhole welding is only exceeded at low welding speed and high laser power

Laser beam welding of copper alloys for e-mobility

Welding with visible wavelengths with respect to the welding depth





Welding with wavelength λ = 450nm

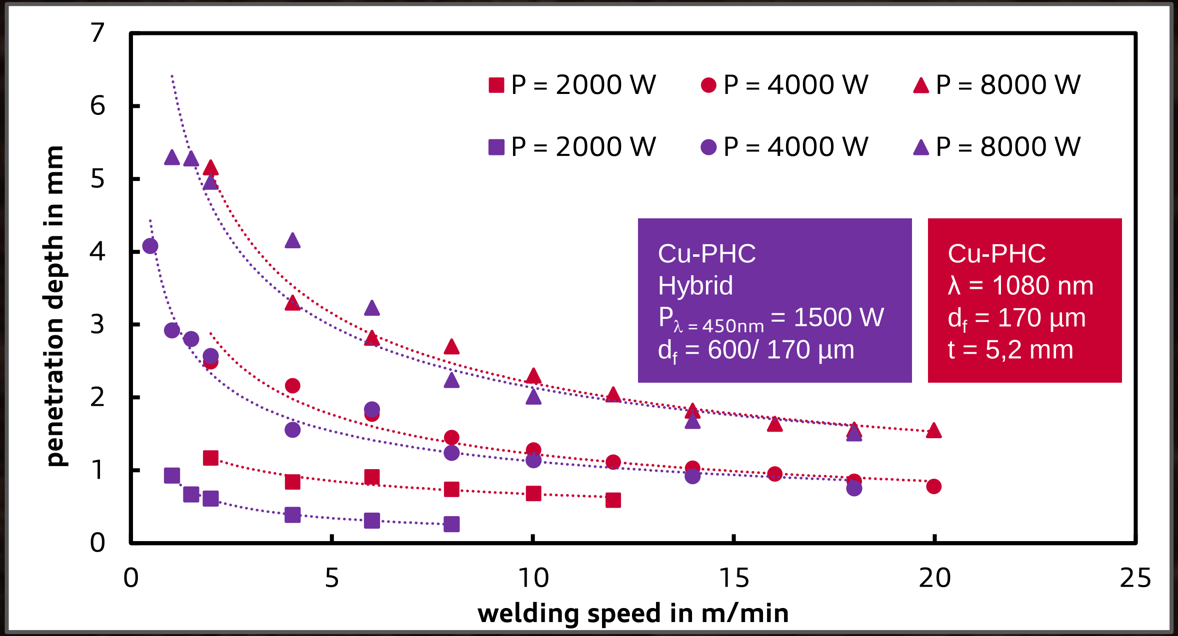
- Achievable penetration depth in investigated parameter field very low
- Threshold for keyhole welding is only exceeded at low welding speed and high laser power

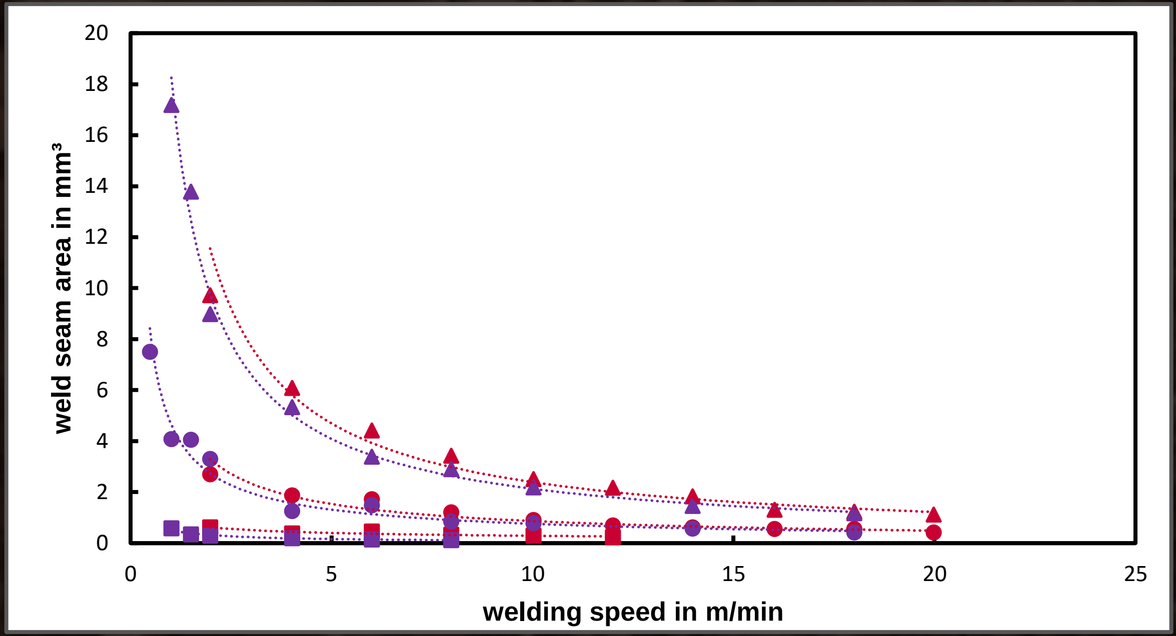
Welding with wavelength λ = 515nm

- Significant increase in penetration depth due to smaller focus diameter and higher output power
- Threshold for keyhole welding is exceeded with P ≥ 1500 W in the entire welding speed range

Laser beam welding of copper alloys for e-mobility

Welding with near infrared wavelengths with respect to the welding depth





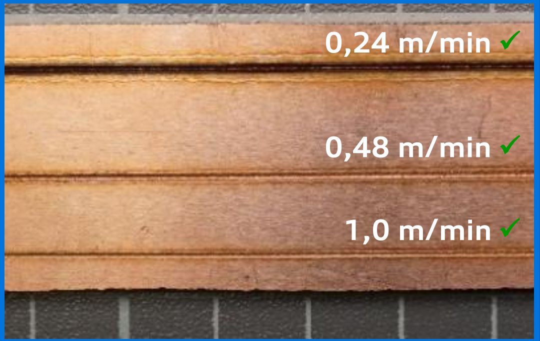
Welding with wavelength λ = 1080nm as well as Hybrid ($P_{\lambda = 450nm}$ = 1500 W = constant)

- Almost all penetration depths with λ = 1080nm are high: t > 1mm
- P = 2000 W: greater penetration depth with λ = 1080nm (Hybrid-process is power dominated with λ = 450nm)
- Increase of penetration depth with increasing laser power independent of wavelength distribution (IR dominant)
- Weld seam area is almost comparable due to same amount of energy input

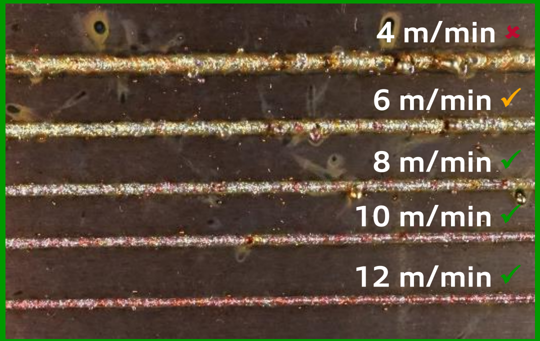
» Seam shaping due to the power ratio of the two superimposed laser beams

Laser beam welding of copper alloys for e-mobility

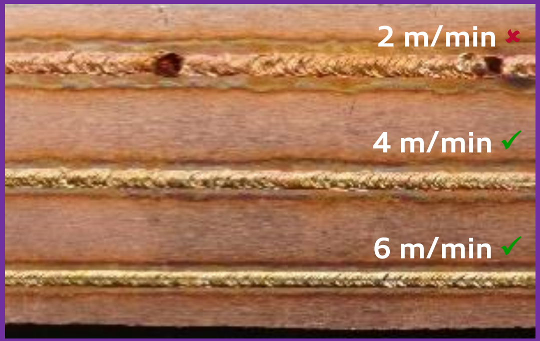
Welding with different wavelengths with respect to the resulting weld quality



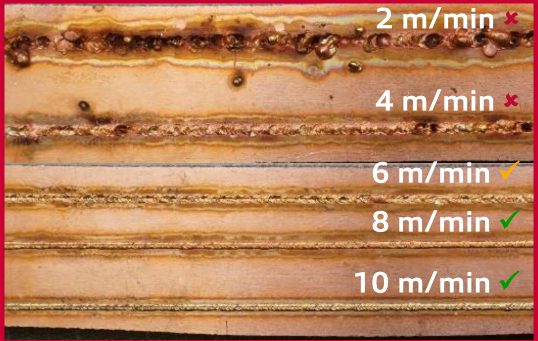
λ = 450nm; P = 1250 W



λ = 515nm; P = 2750 W



Hybrid; P = 6000 W
($P_{\lambda = 450nm}$ = 1500 W)



λ = 1080 nm; P = 6000 W

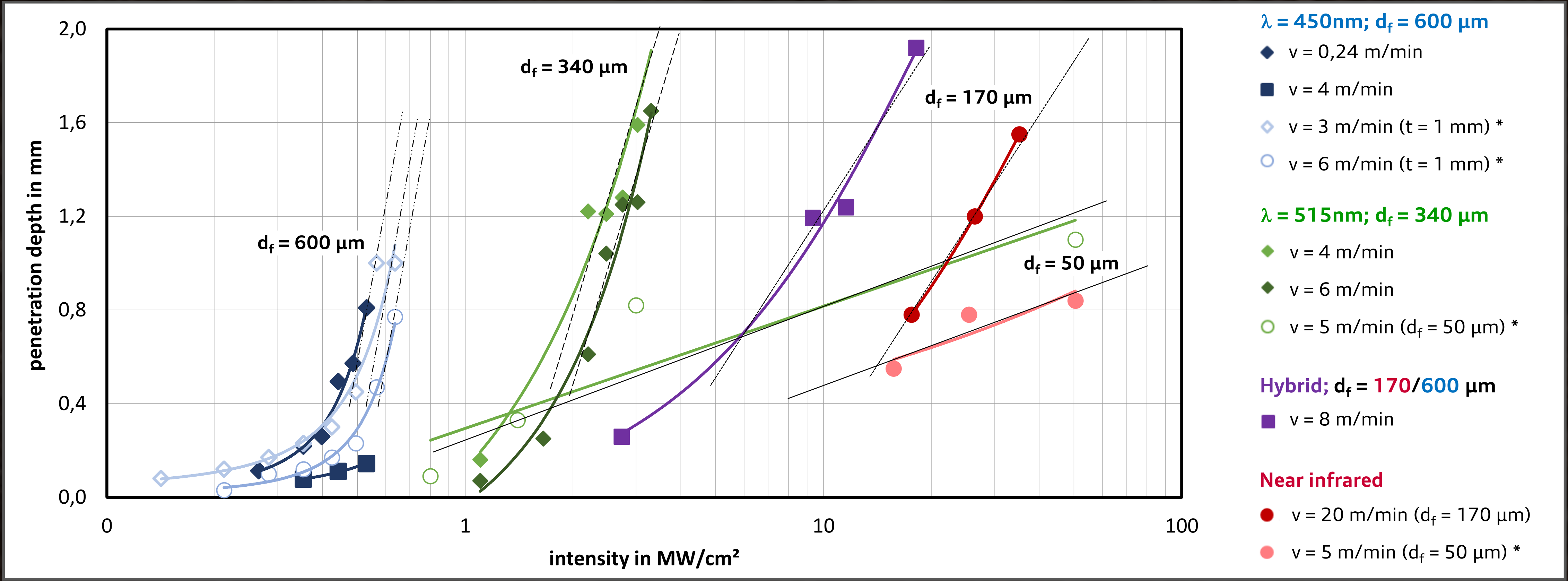
Challenging weld defects are melt ejection, spatter formation, pore formation ...

- λ = 450nm: stable process, smooth surface, no spatters and pores due to heat conduction welding
- λ = 515nm: keyhole welding with spatter and pore formation at low welding speed
- λ = 1080nm: keyhole welding with spatter and pore formation at low welding speed,
  heat conduction welding is not stable/ possible
- Hybrid ($P_{\lambda = 450nm}$ = 1500 W): due to amount of visible wavelength improved weld quality at lower welding speed

» Possible process strategies to reduce weld defects at keyhole welding are increased power AND speed

Laser beam welding of copper alloys for e-mobility

Influence of different wavelengths on deep penetration threshold



- Penetration depth < 0,5 mm only with visible wavelengths possible (heat conduction welding)
- The shorter the wavelength the smaller the intensity for keyhole welding (threshold)
- The smaller the focus diameter the smaller the increase in depth (increase in process stability)

** source: T. Hesse: Laser welding with kW power in the visible wavelength range, TRUMPF GmbH + Co. KG, European Automotive Laser Applications 2020*
C. Ullmann: Blue high-power Diode Lasers in the multi kW Range for new Process Capabilities in Welding of Materials for Electromobility, Laserline GmbH, European Automotive Laser Applications 2020

Laser beam welding of copper alloys for e-mobility

Summary

Visible wavelengths (λ = 450nm and λ = 515nm)

advantages	disadvantages
very high absorptivity and coupling efficiency	high thermal losses due to predominant conductive heat flow using large focus diameter or low welding speed
precise setting of parameters for penetration depth from **50 µm up to 1 mm**	beam quality determines the use of optics (exemplary large working distance usability of scanner)
high weld quality at heat conduction welding	high investment costs
	use of shielding gases increases the process efficiency at keyhole welding (plasma absorption)

Near infrared wavelengths (λ = 1080nm)

advantages	disadvantages
high process efficiency and associated weld quality with increased welding speed and laser power	minimal **penetration depth > 1 mm** (v ↑ und P ↑)
high beam quality enables the use of scanner	
comparatively low investment cost	

Thank you!

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