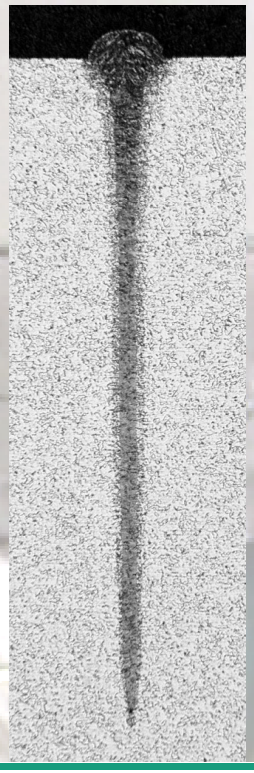
Innovations in laser welding using high brightness lasers



E. Beyer[1, 2], J. Standfuss[1]

[1] Fraunhofer IWS Dresden
Winterbergstr. 28, 01277 Dresden, Germany
[2] Technische Universitaet Dresden,
01062 Dresden, Germany

Heriot-Watt IMRC Conference,
26th June 2012, Edinburgh

Fraunhofer IWS Dresden

New brilliant single mode fiber laser sources

- Single mode fibre laser up to 3kW for commercial use available (10 kW at laboratory)
- Excellent beam quality allows welding applications with spot size of 20..40µm with intensity level higher than electron beam

Challenge for welding using high brightness lasers:

- Extended process know how for new welding applications
- New adapted laser optics, beam shaping and scanning concepts

<u>Aim:</u> **New innovative laser welding applications**

Laser-assisted Plasma Arc Welding

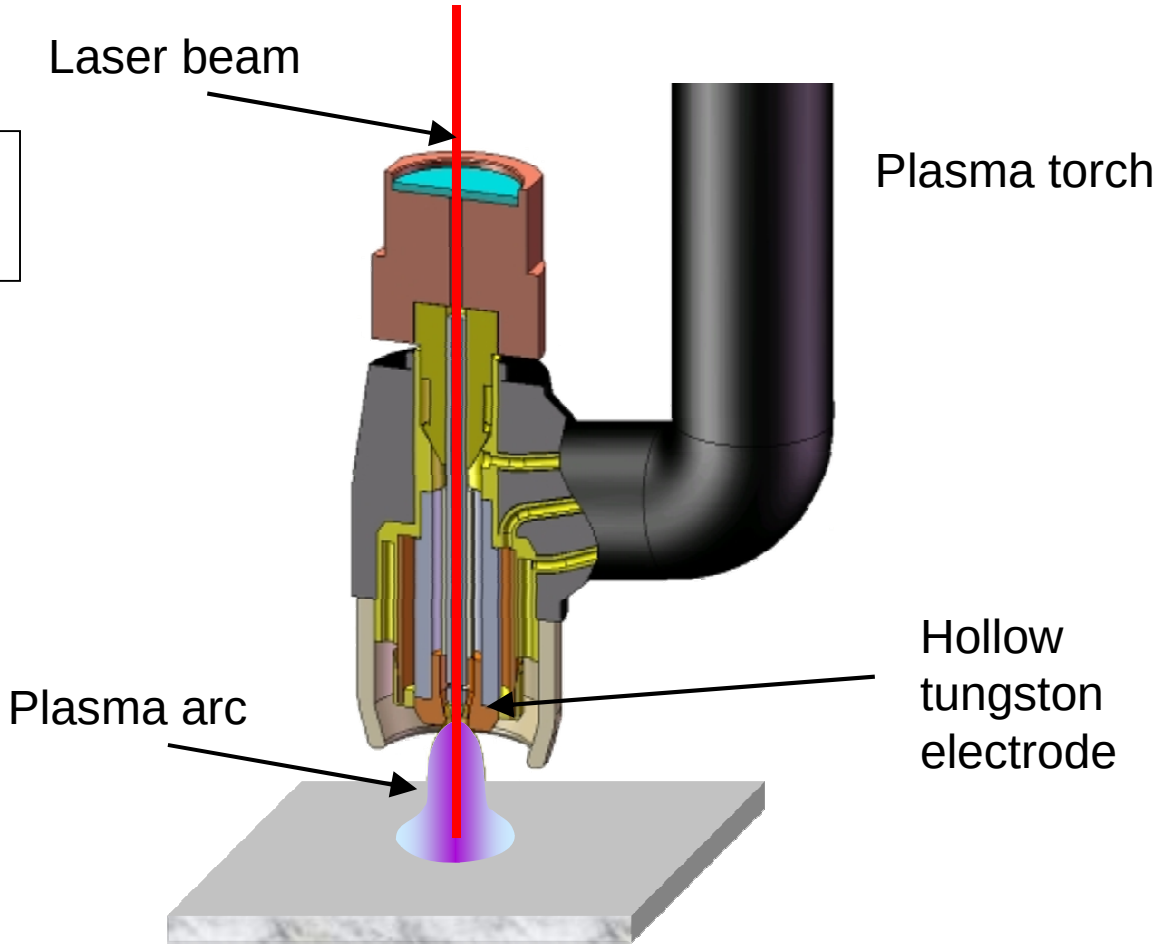
BPP < 0.34 mm mrad^{-1}

Focus diameter = 240 micron

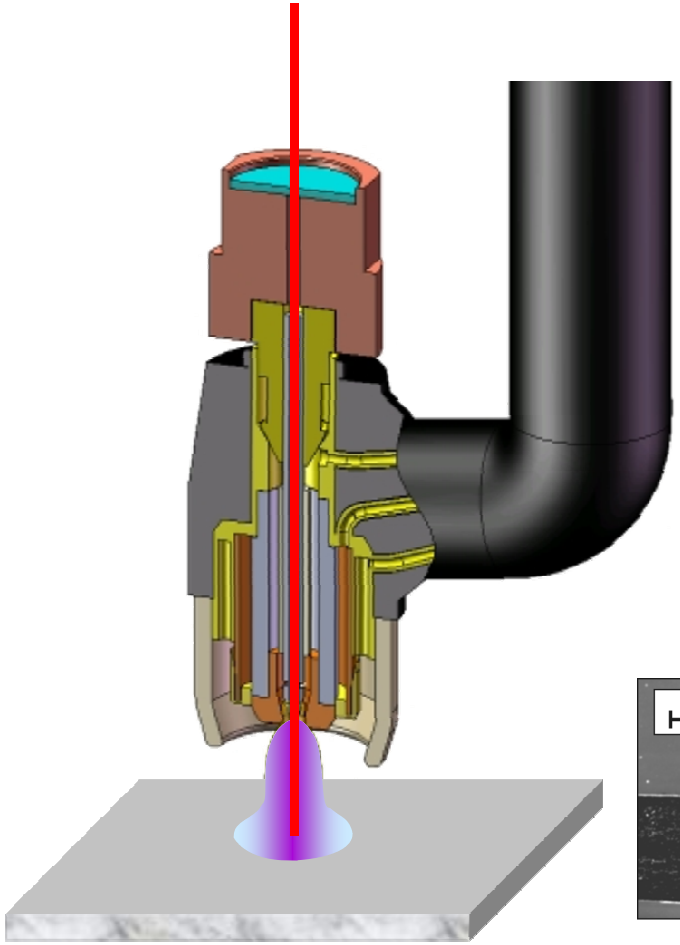
DCEN mode
(direct current – electrode negative)

Plasma gas = Argon

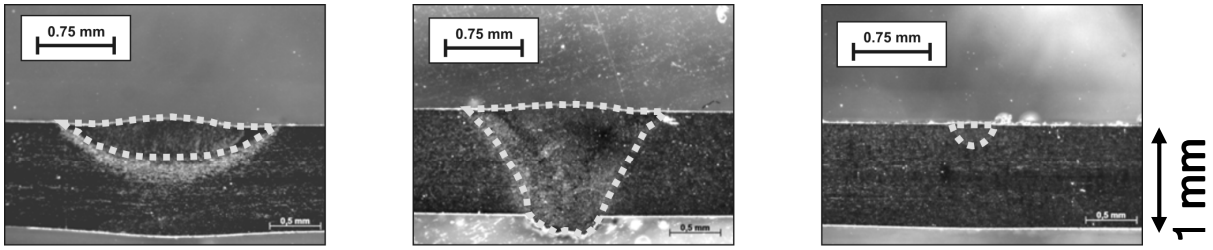
Shielding gas = Argon



Laser-assisted Plasma Arc Welding



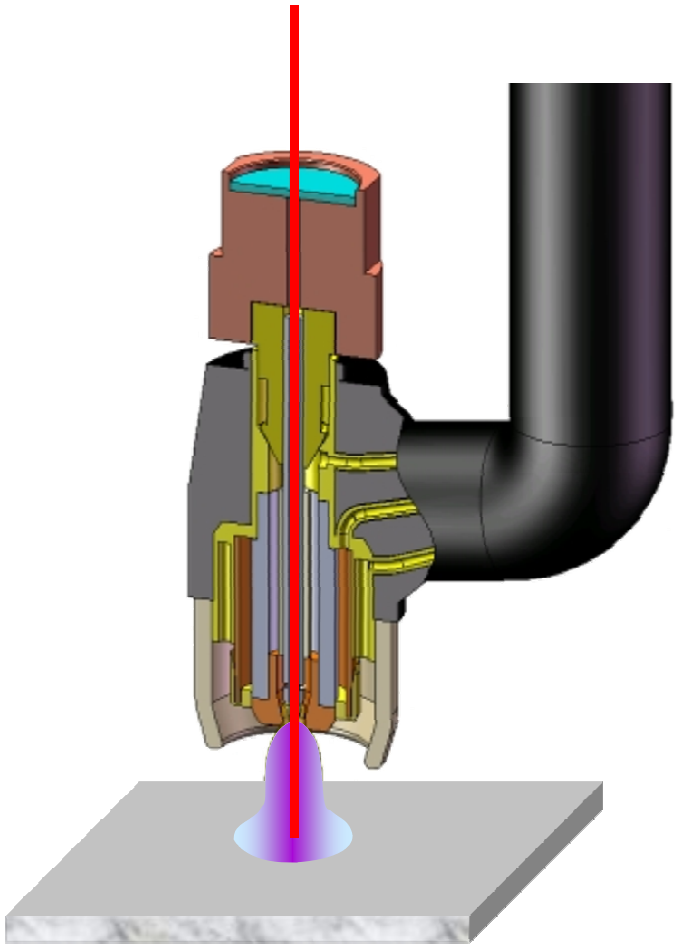
Welding AISI 304 stainless steel:
Arc amperage = 40 A (800 W),
laser power = 200 W,
welding speed = 0.75 m per min,
sheet thickness = 1 mm

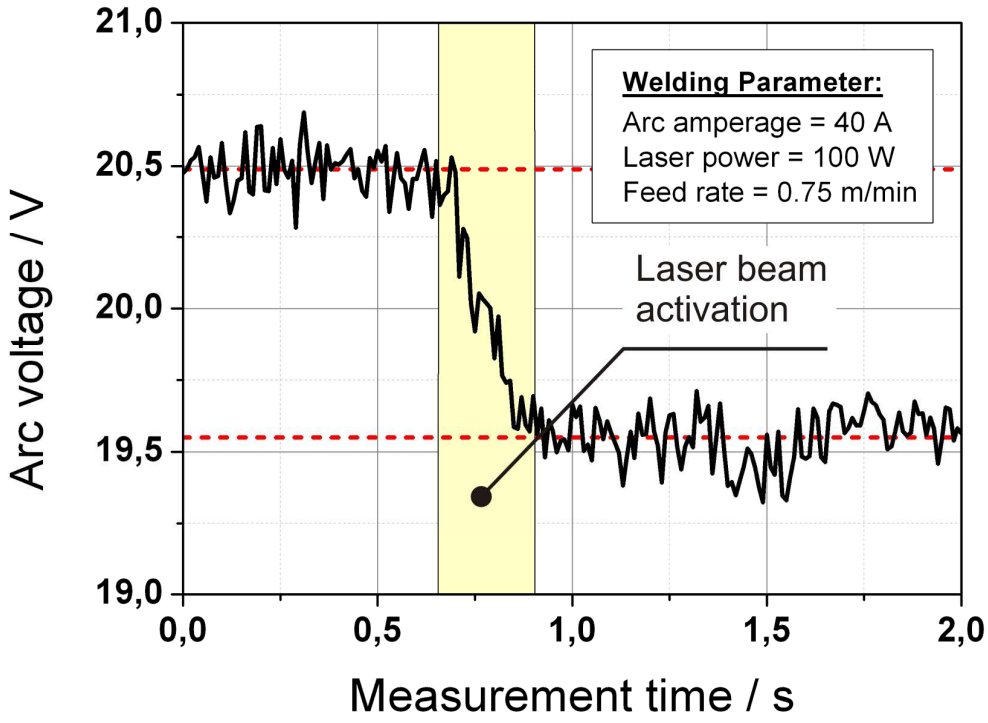


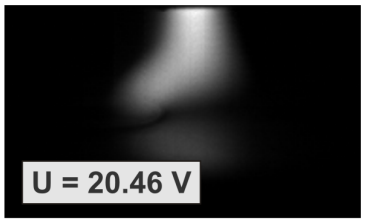
Plasma | Plasma + Laser | Laser

Laser-assisted Plasma Arc Welding

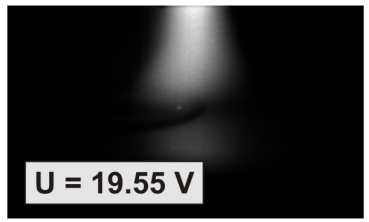
AISI 304 Stainless Steel







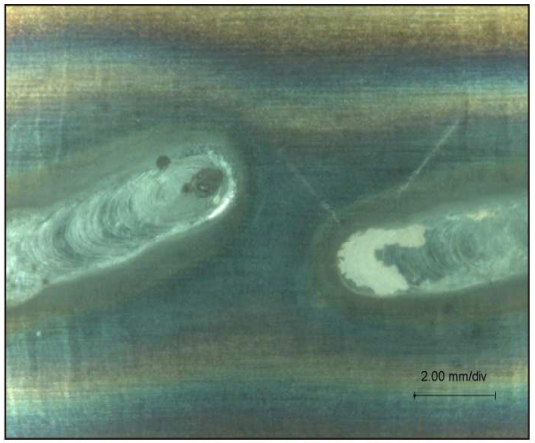
Plasma

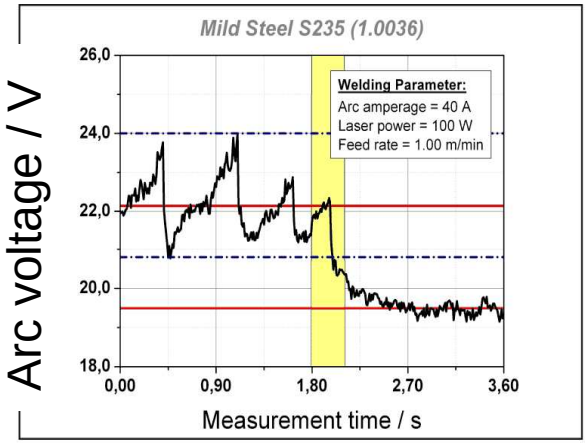


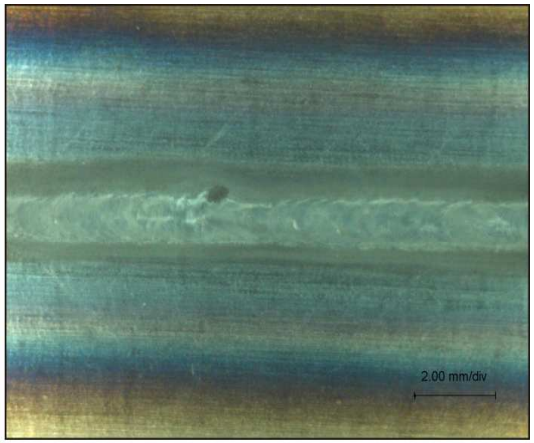
Plasma + Laser

Arc stabilisation in steel welding

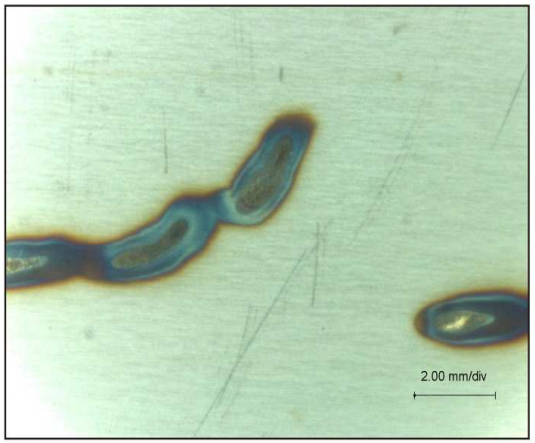
Mild Steel

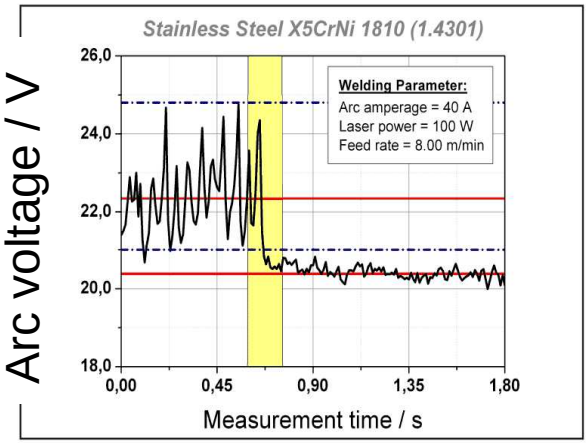


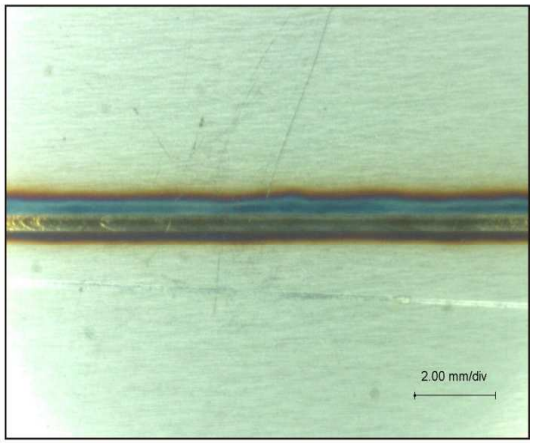




Stainless Steel



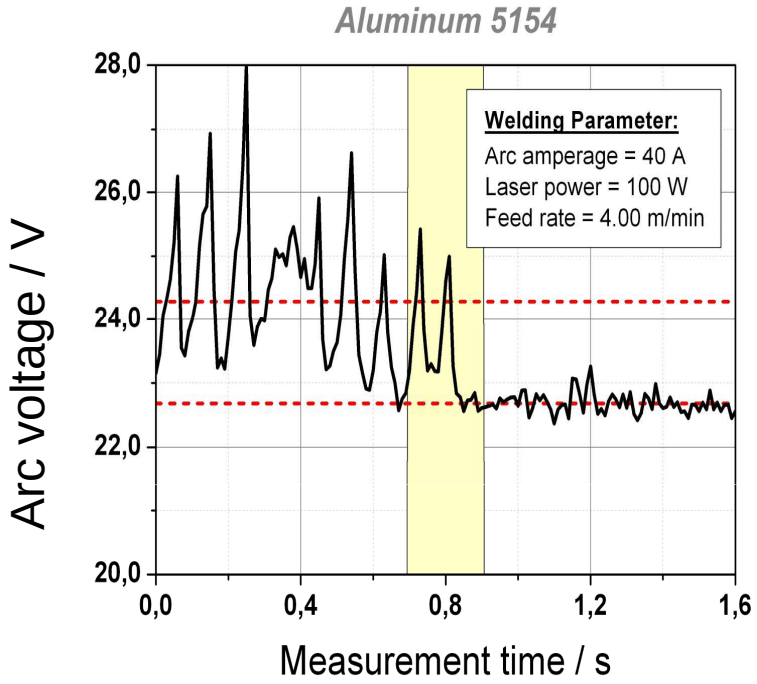


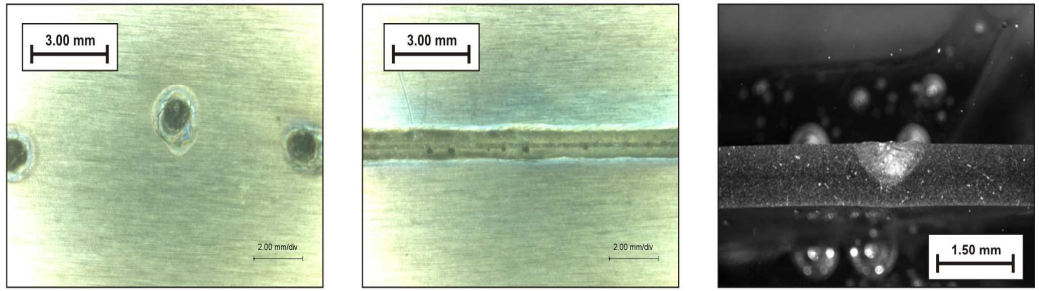


Plasma

Plasma + Laser

Arc stabilisation in aluminium welding





Plasma | Plasma + Laser | Plasma + Laser

Welding aluminum 5154:
Arc amperage = 40 A (900 W),
laser power = 100 W,
welding speed = 4.0 m per min,
sheet thickness = 1 mm

New brilliant single mode fiber laser sources

- Single mode fibre laser up to 3kW for commercial use available (10 kW at laboratory)
- Excellent beam quality allows welding applications with spot size of 20..40µm with intensity level higher than electron beam

Challenge for welding using high brightness lasers:

- Extended process know how for new welding applications
- New adapted laser optics, beam shaping and scanning concepts

<u>Aim:</u> **New innovative laser welding applications**

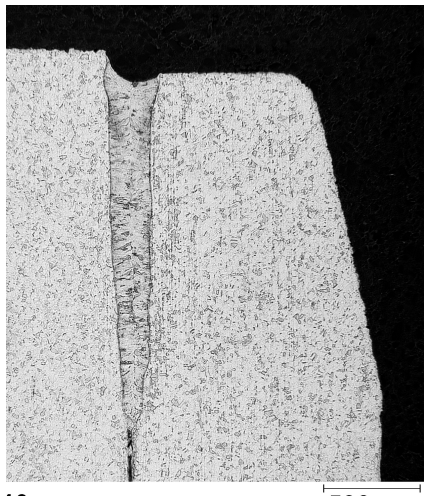
Welding of Heat Sensitive Components:

Problems

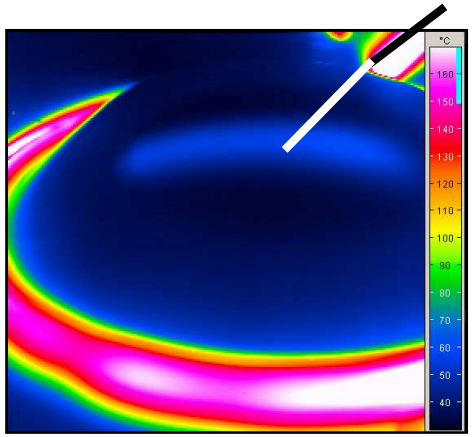
- weld temperature field can cause thermal damage at
  - ball bearings
  - integrated sensors
  - electronic components to be sealed

Solution

- welding with lowest energy input per unit length



$T < 70℃ < T_{critical}$ (120℃)

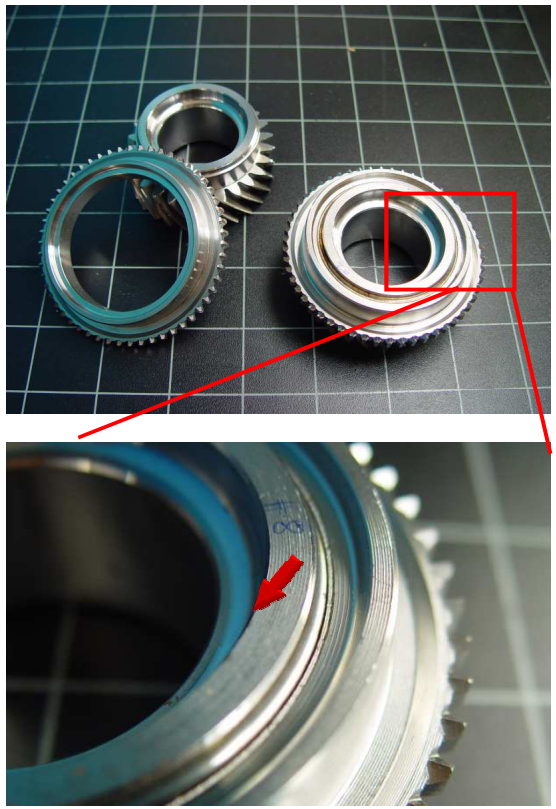


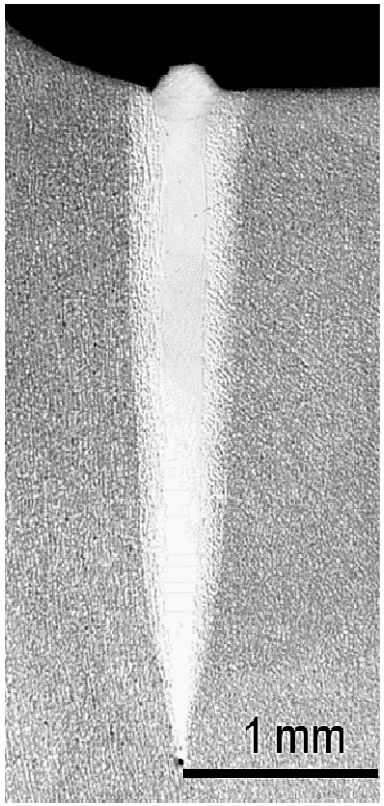
opened, thermal image

Application example: gear – clutch connector weld

- Thin and deep welding seams for low distortion of gear parts

1 kW fiber laser





New brilliant single mode fiber laser sources

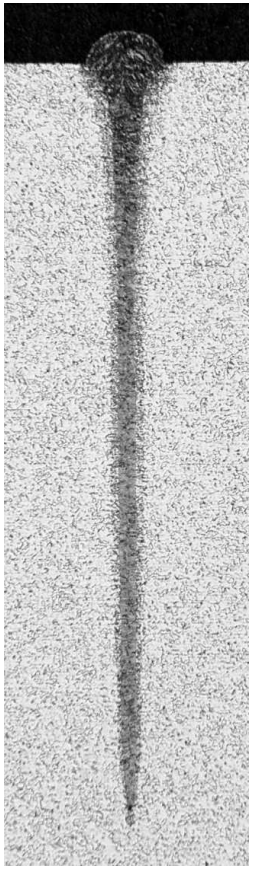
- Single mode fibre laser up to 3kW for commercial use available (10 kW at laboratory)
- Excellent beam quality allows welding applications with spot size of 20..40µm with intensity level higher than electron beam

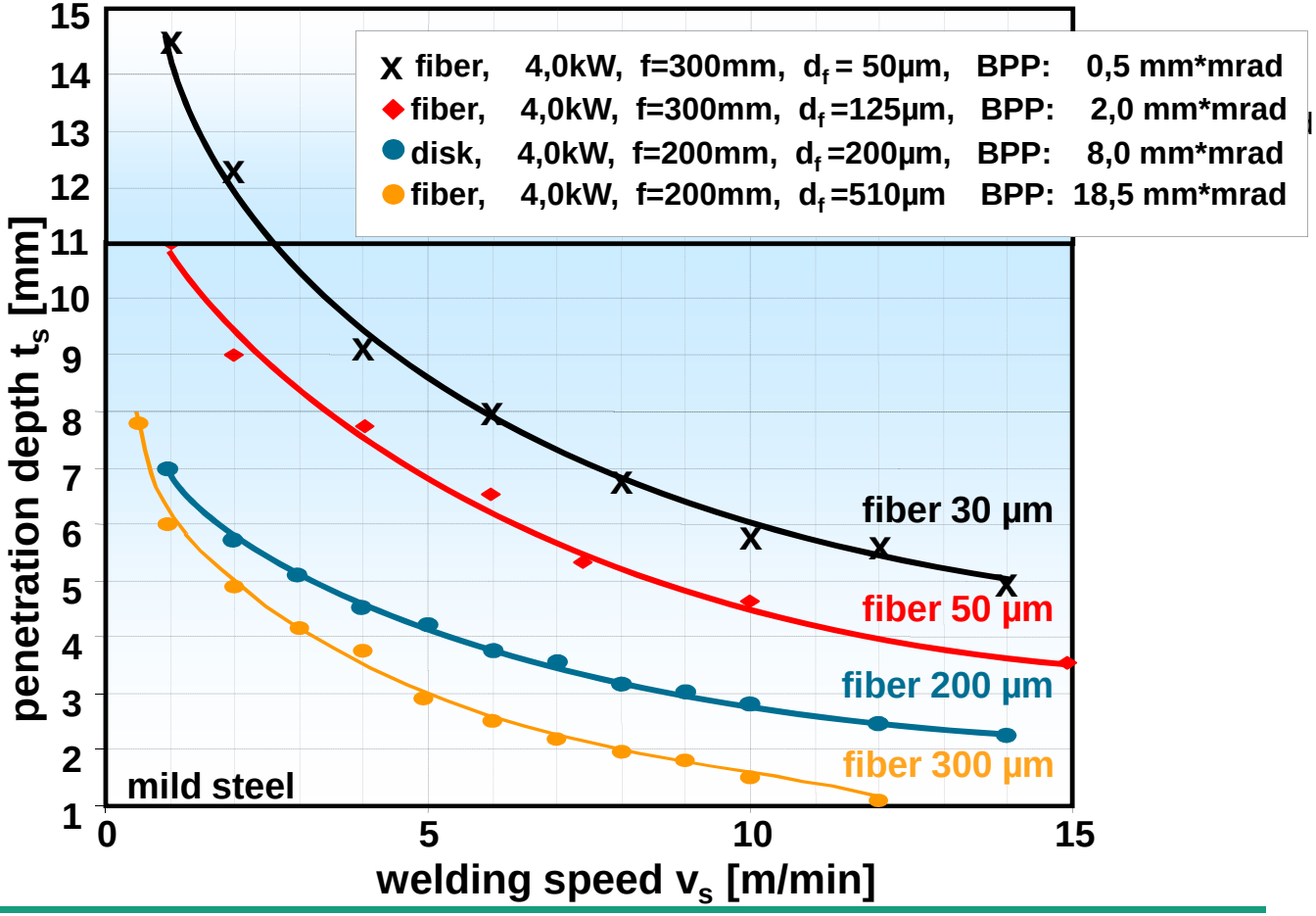
Challenge for welding using high brightness lasers:

- Extended process know how for new welding applications
- New adapted laser optics, beam shaping and scanning concepts

<u>Aim:</u> **New innovative laser welding applications**

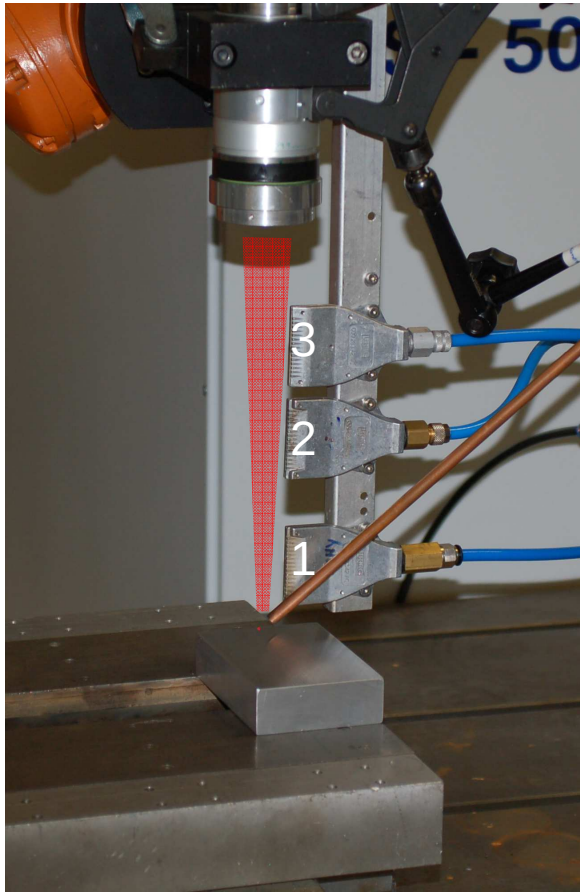
Comparison of Welding Results with Different Beam Qualities

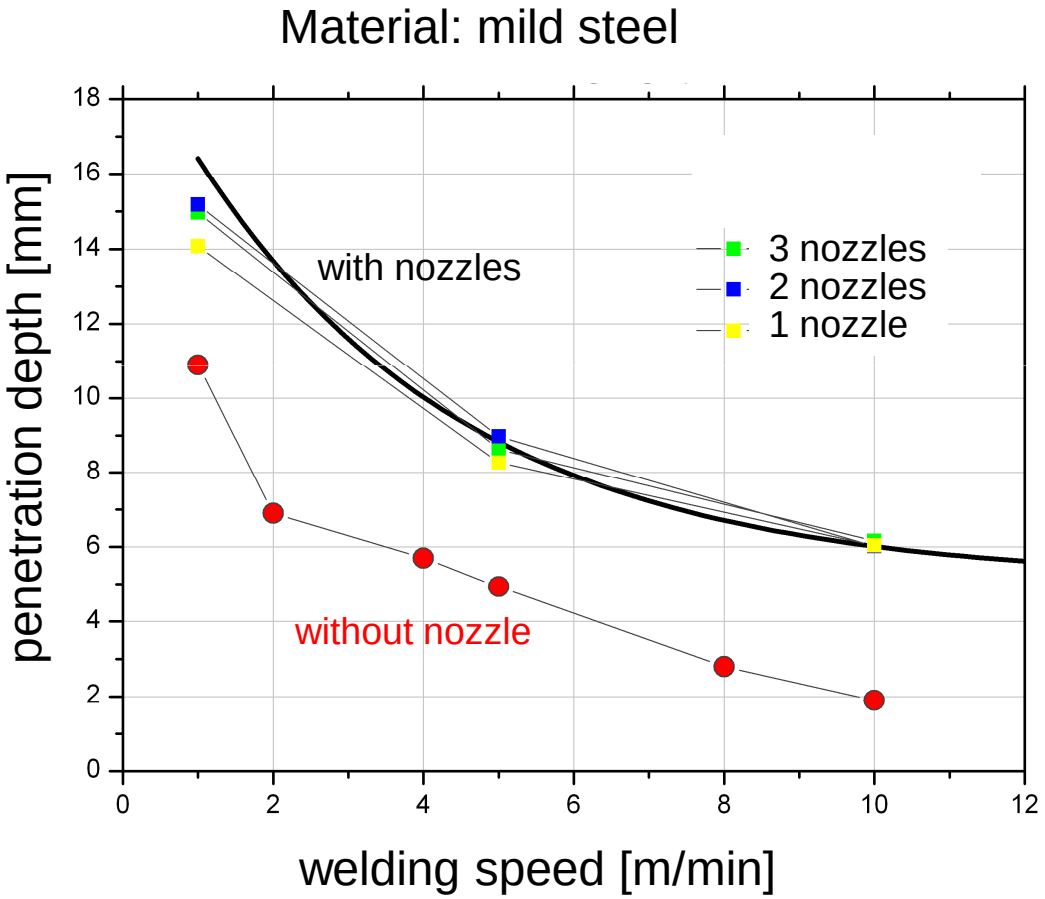




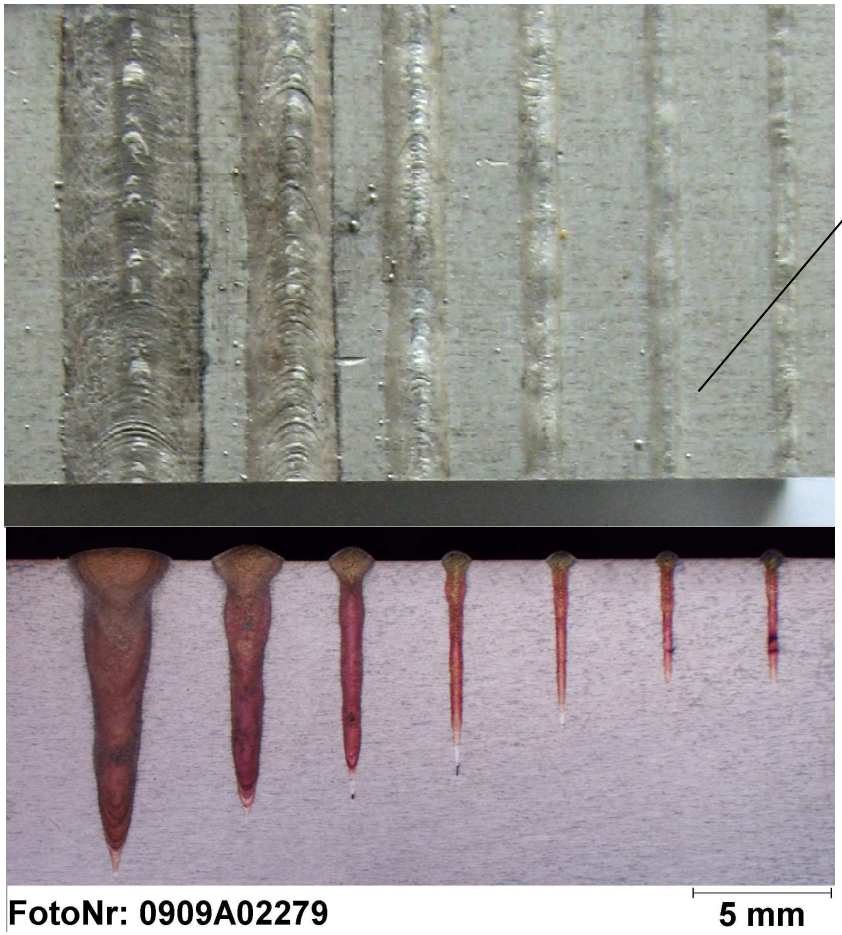
Fraunhofer IWS Dresden

Welding with 5 kW Fraction Limited Fiber Laser

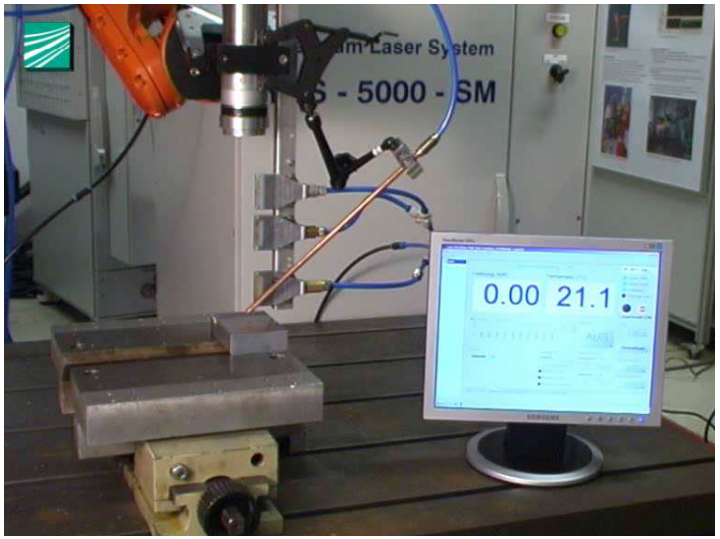




Welding with 5 kW Fraction Limited Fiber Laser



welding of AlMg3,
focal length 300mm,
power 5 kW, shielding gas He
speed 1-20 m/min



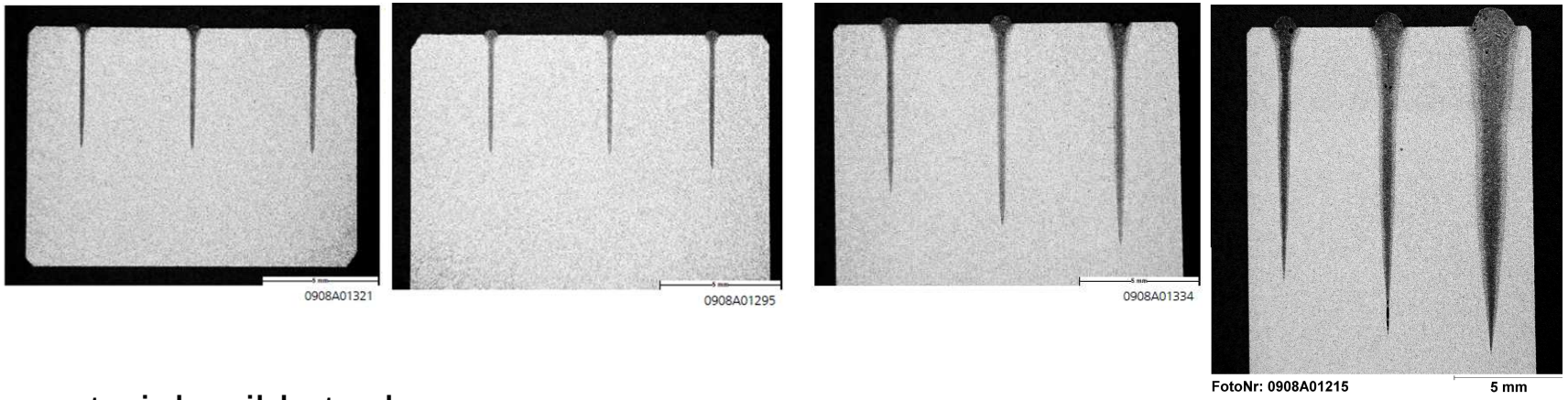
video

Welding with 5 kW Fraction Limited Fiber Laser

Power 5 kW, BBP 0,5 mm*mrad, focal position 0, focal length 300mm

welding speed in m/min

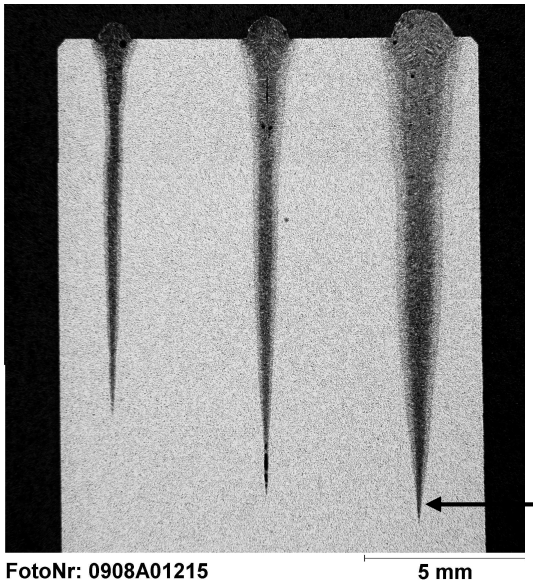
20 18 16 14 12 10 8 6 4 3 2 1

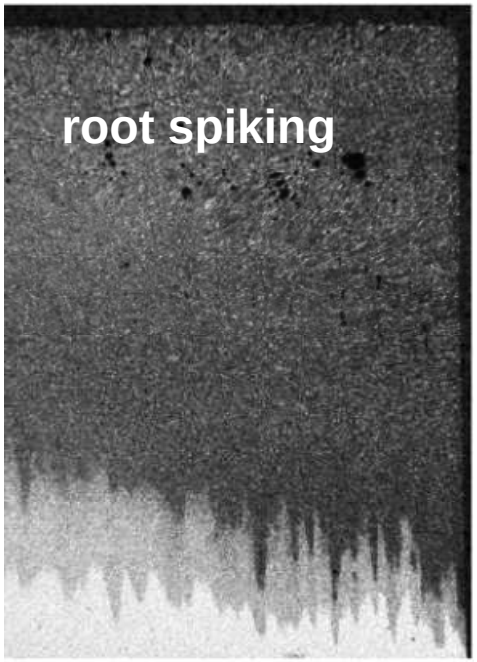


material: mild steel

Welding with 5 kW Fraction Limited Fiber Laser

Power 5 kW, BBP 0,5 mm*mrad, focal position 0, focal length 300mm





material: mild steel

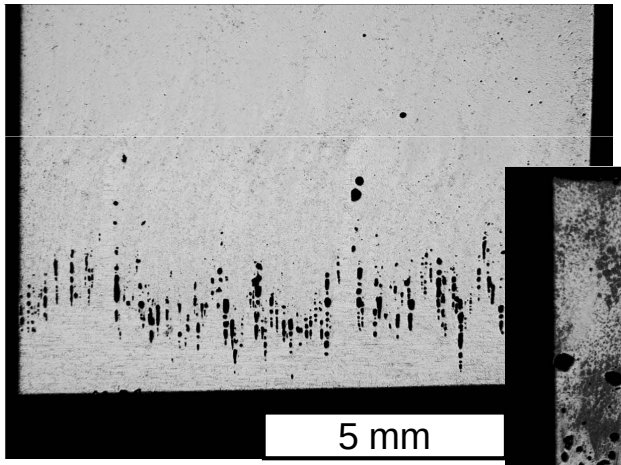
Spiking phenomena for welding with high power single mode fibre lasers

- Spiking phenomena independent from the welded material

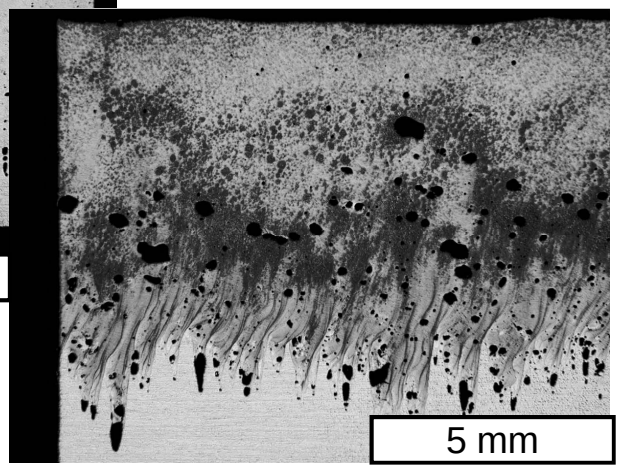
AND

- Independent from the used beam source (laser or electron beam)

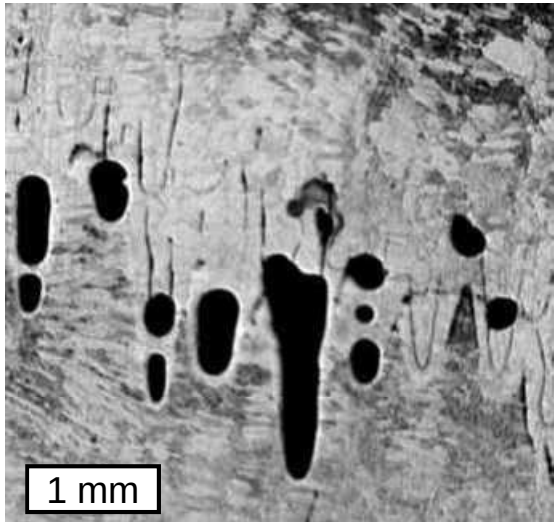
Stainless steel (LBW)



Aluminium (LBW)



Titan (EBW)

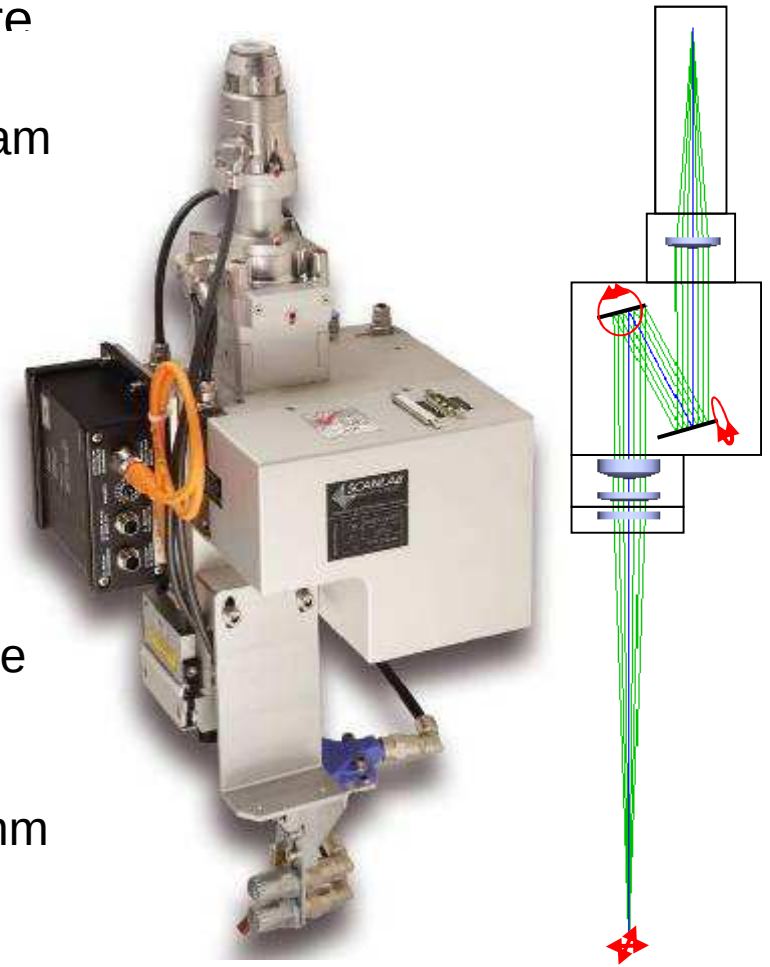


Source: MTU Aero Engines (München)

Laser Beam Tool for high dynamic 2D beam oscillation

Integrated solution for the use of brilliant laser sources for welding of dissimilar metals with reproducible mixture

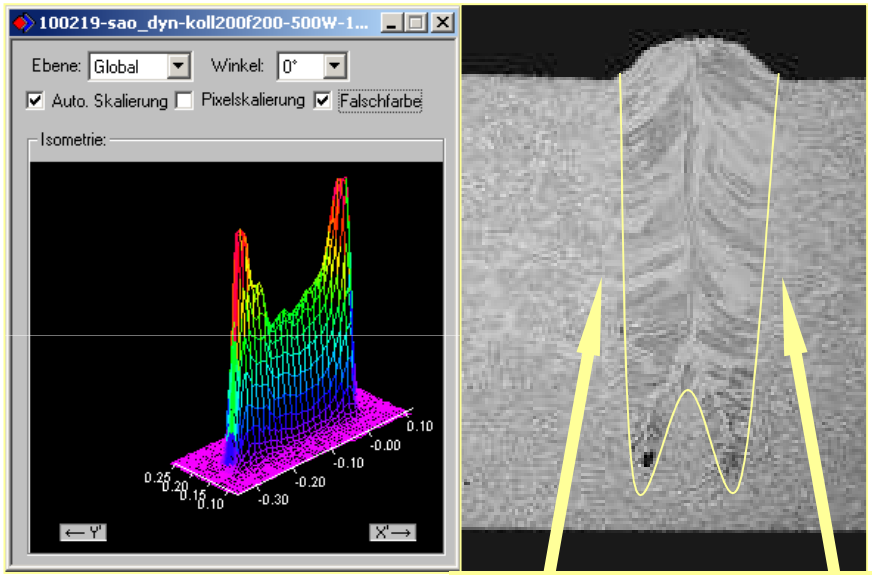
- High dynamic 2D beam oscillation and seam position control / frequency > 2kHz
- Scan field: 10x10 mm^2
  (High dynamic range: 1,5x1,5 mm^2)
- laser power max. 4 kW (single mode)
- Integrated seam tracking system
  - Highly dynamic and exact, inexpensive
  - Defined beam positioning up to 20 m/min welding speed
  - Minimal look-ahead distance of 1..5 mm



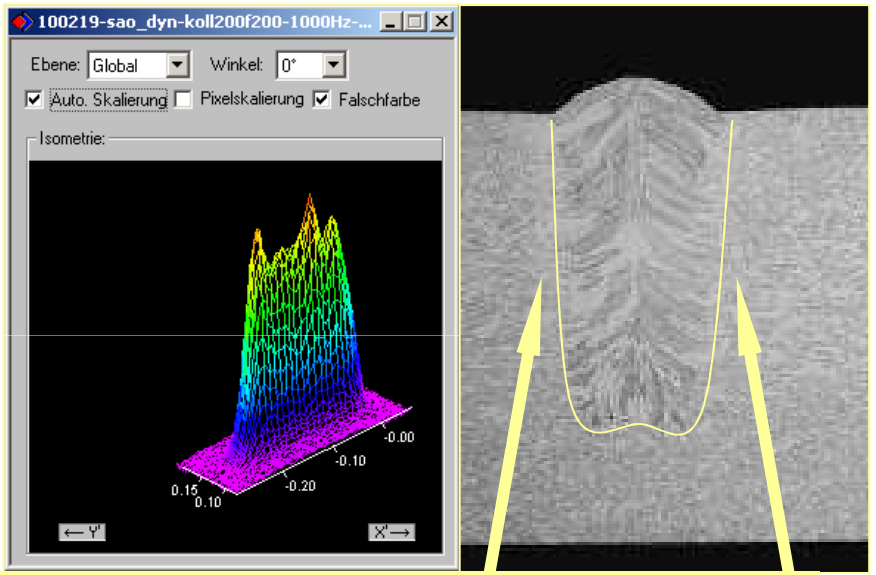
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Laser Beam Tool for high dynamic beam oscillation

without power modulation



with power modulation



<u>Nearly parallel fusion lines:</u> condition for

Welding of dissimilar metals with adjustable mixture

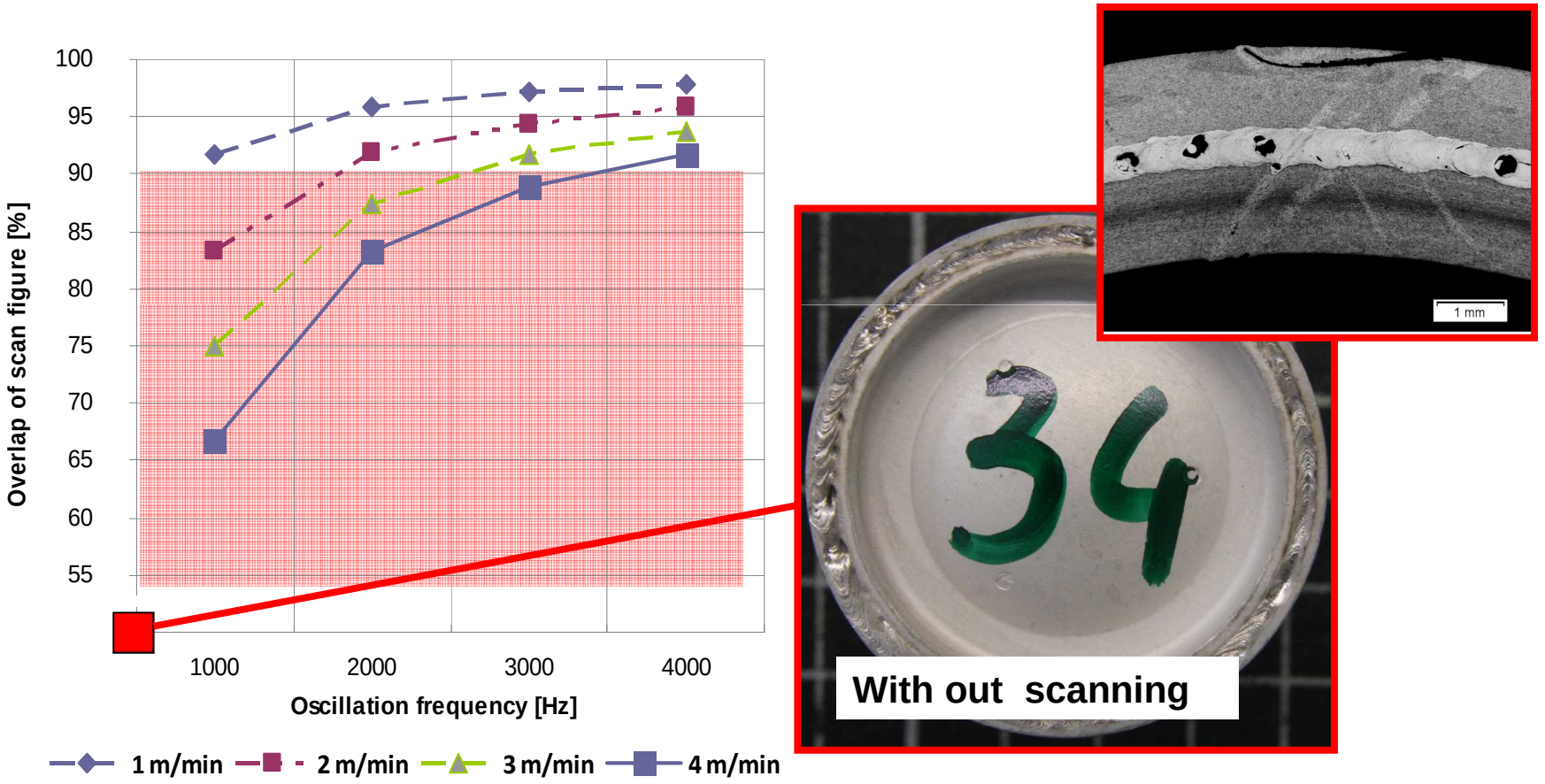
Solution:

beam oscillation with position coupled power modulation up to 4 kHz

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

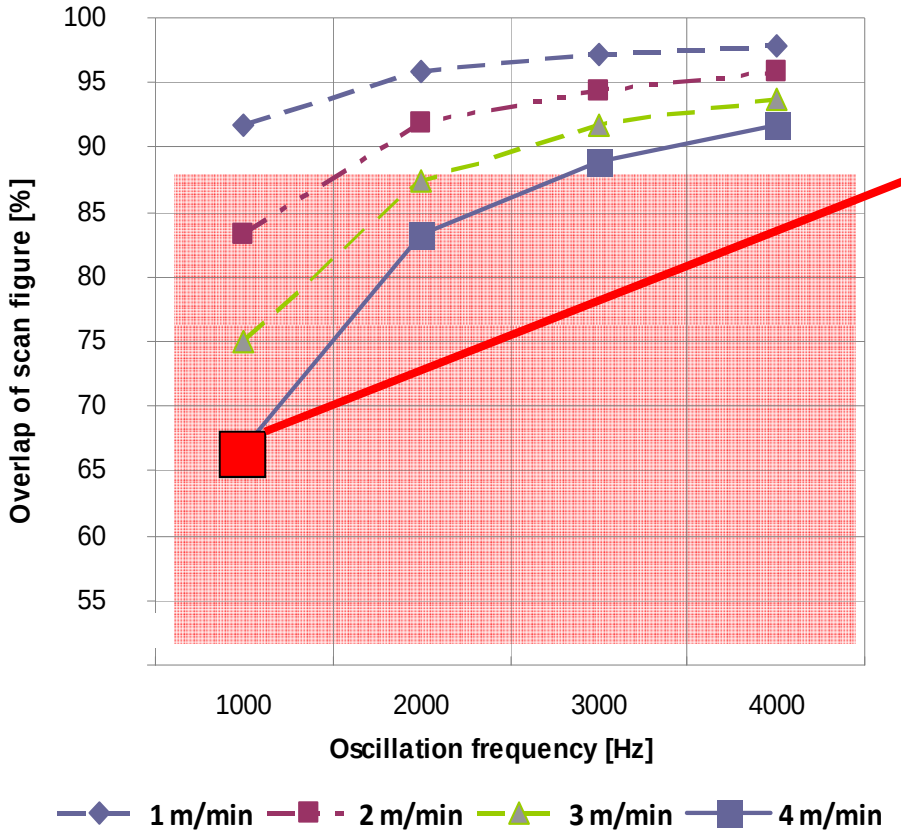
Improved weld quality by high speed scanning

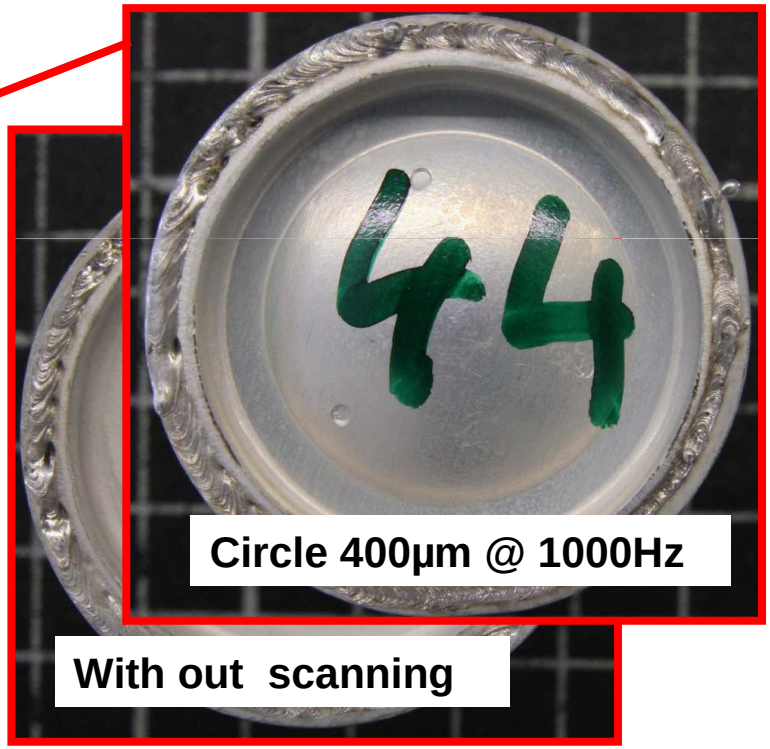
Application:
Cooling components, Al3003/3103, contaminated with flux



Improved weld quality by high speed scanning

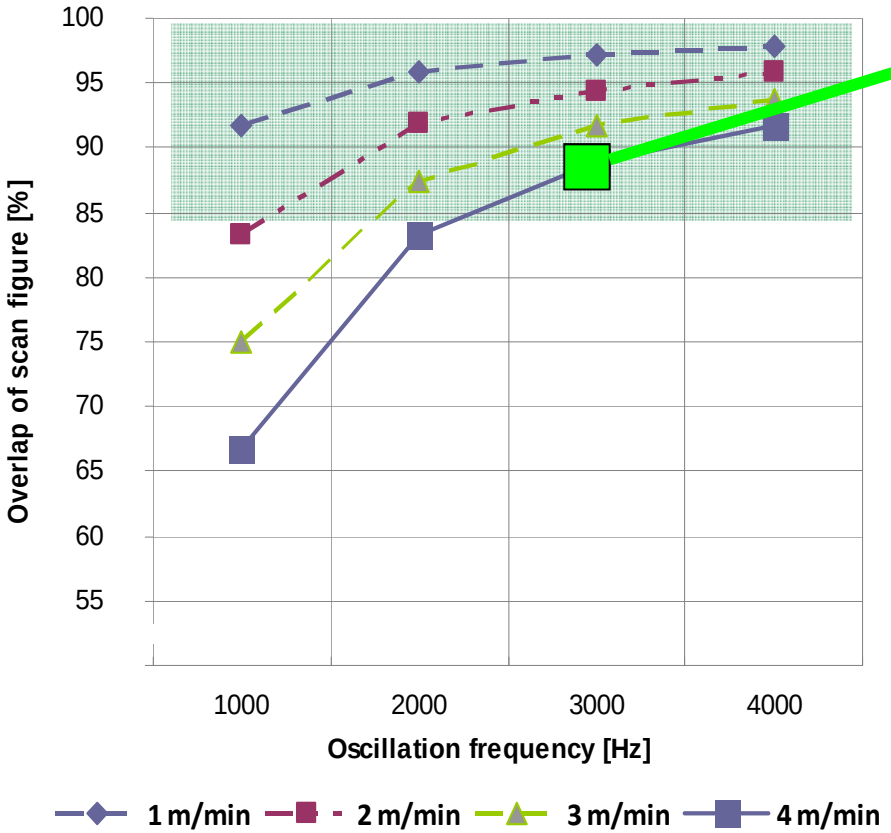
Application:
Cooling components, Al3003/3103, contaminated with flux

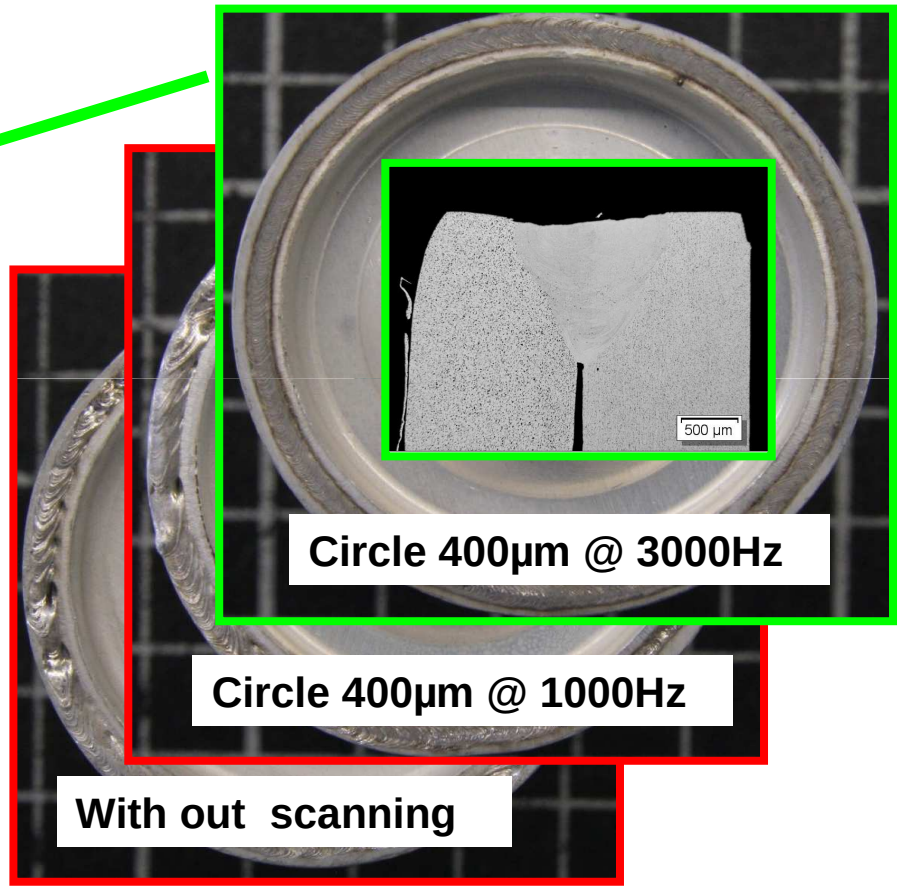




Improved weld quality by high speed scanning

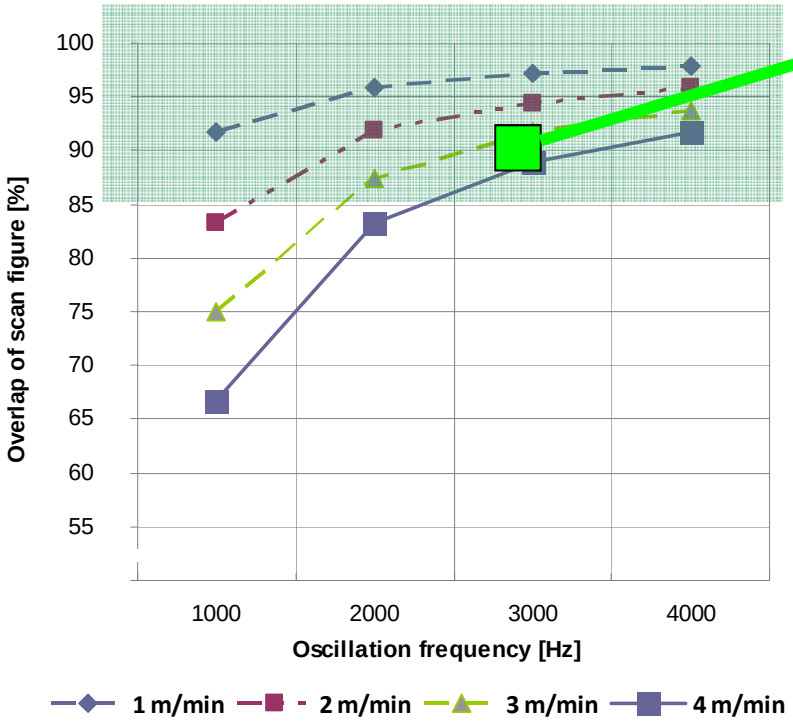
Application:
Cooling components, Al3003/3103, contaminated with flux

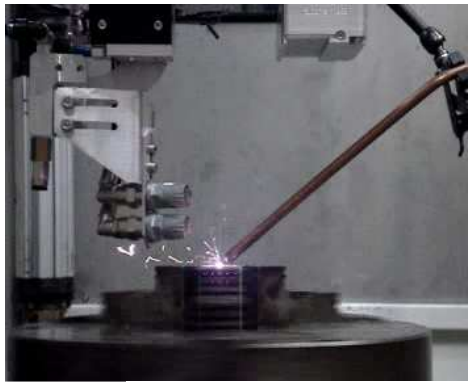




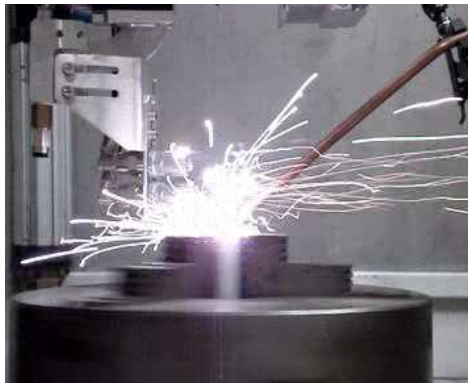
Improved weld quality by high speed scanning

Application:
Cooling components, Al3003/3103, contaminated with flux





Circle 400µm @ 3000Hz **With scanning**



With out scanning

Improved weld quality by high-frequency beam oscillation

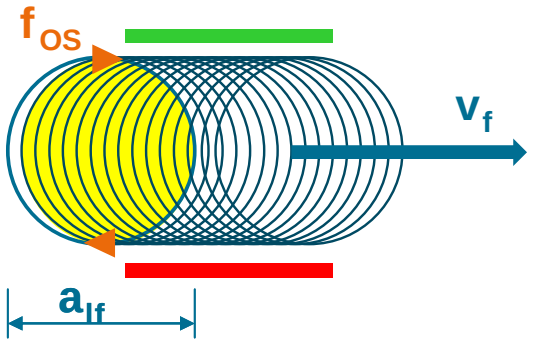
Basic Investigation:
low oscillation frequency / low overlap leads to instable welding process

Parameter:

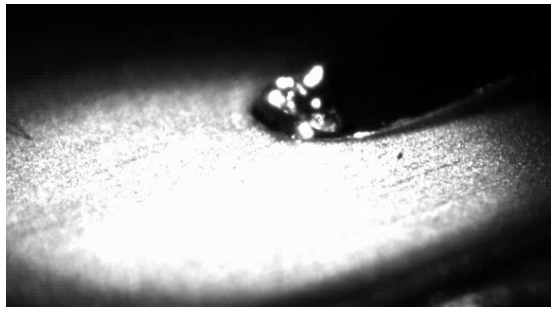
V_f = 2 m/min

a_{lf} = 200 µm

stainless steel



f_{os} = 1000Hz | **f_{os} = 2000Hz** | **f_{os} = 3000Hz**



GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Fraunhofer IWS Dresden

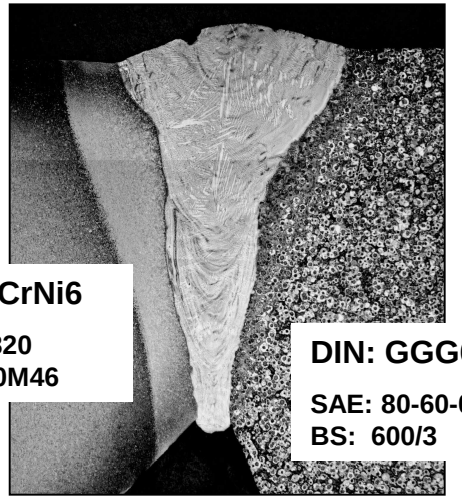
Weldability of cast-iron / steel dilution welds

Potential application:

Differential gear

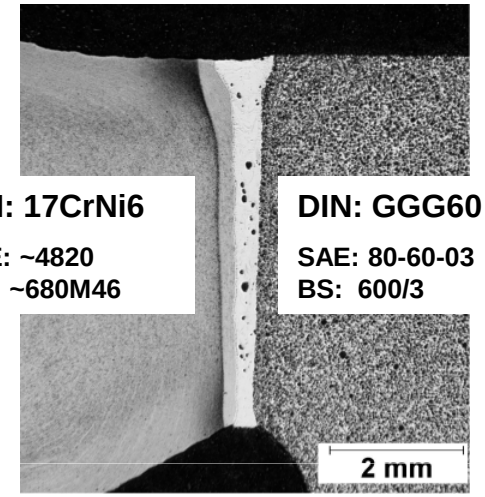
Example:

GGG 60 / 17CrNi6-6



series standard:

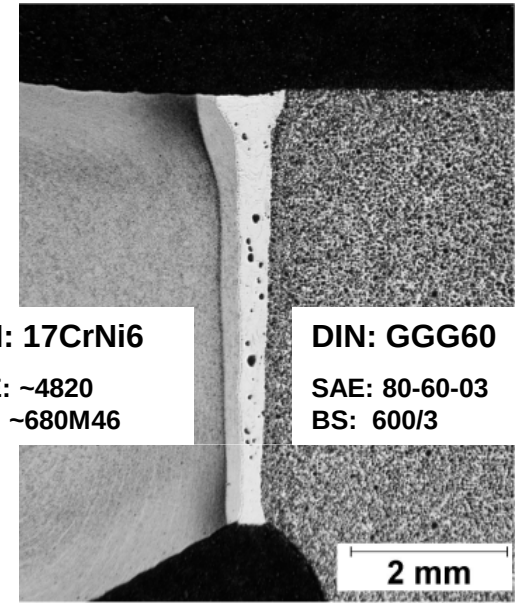
CO_2-Laser
6.0 kW
v_S= 1.3 m/min
with filler wire
welding time 21 s



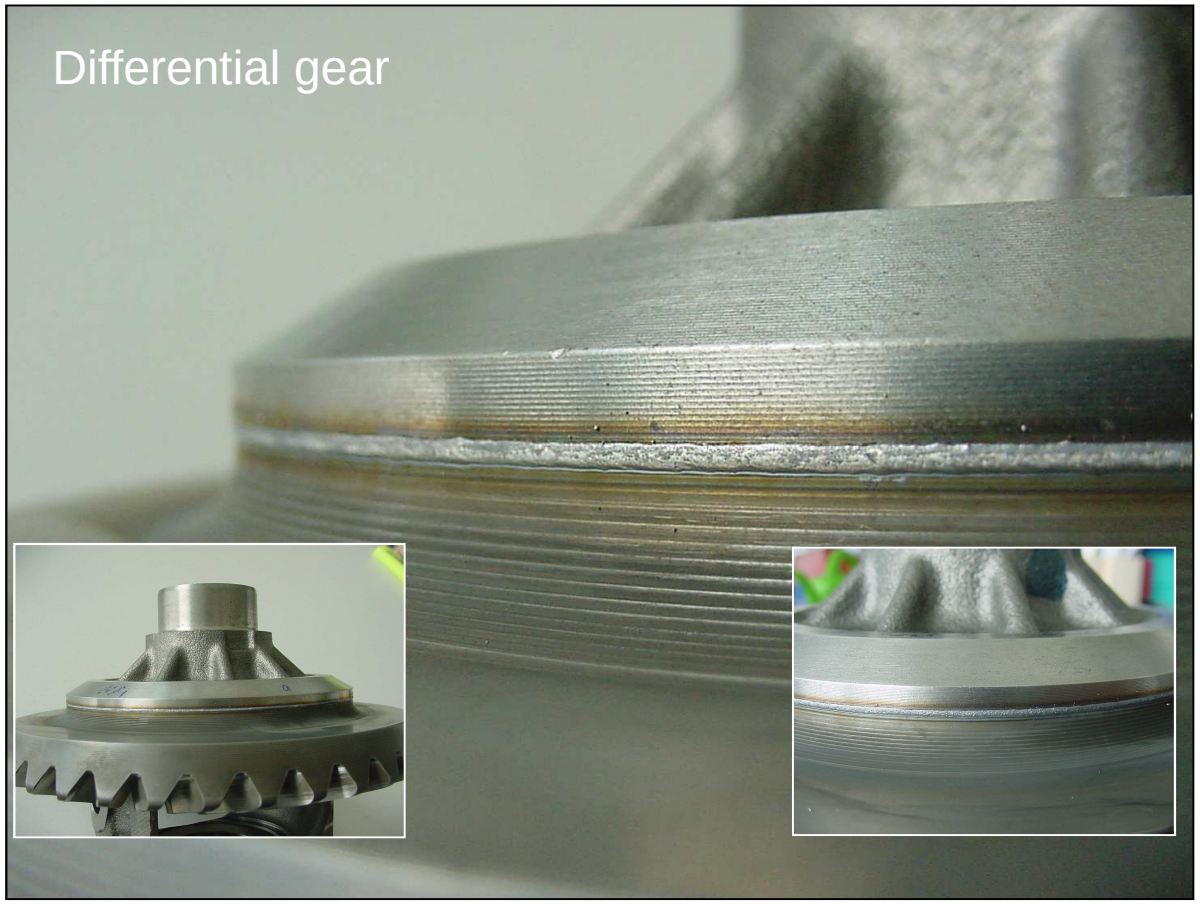
lab results:

fiber laser
4.0 kW
v_S = 4.5 m/min
without filler wire
welding time: 6 s

Laser beam welding with fiber laser

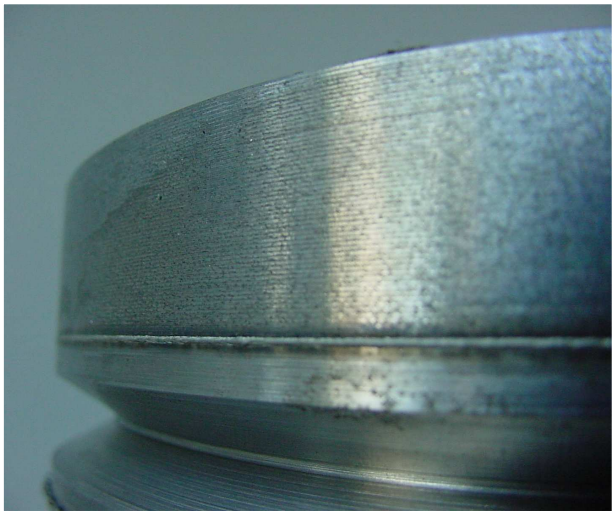


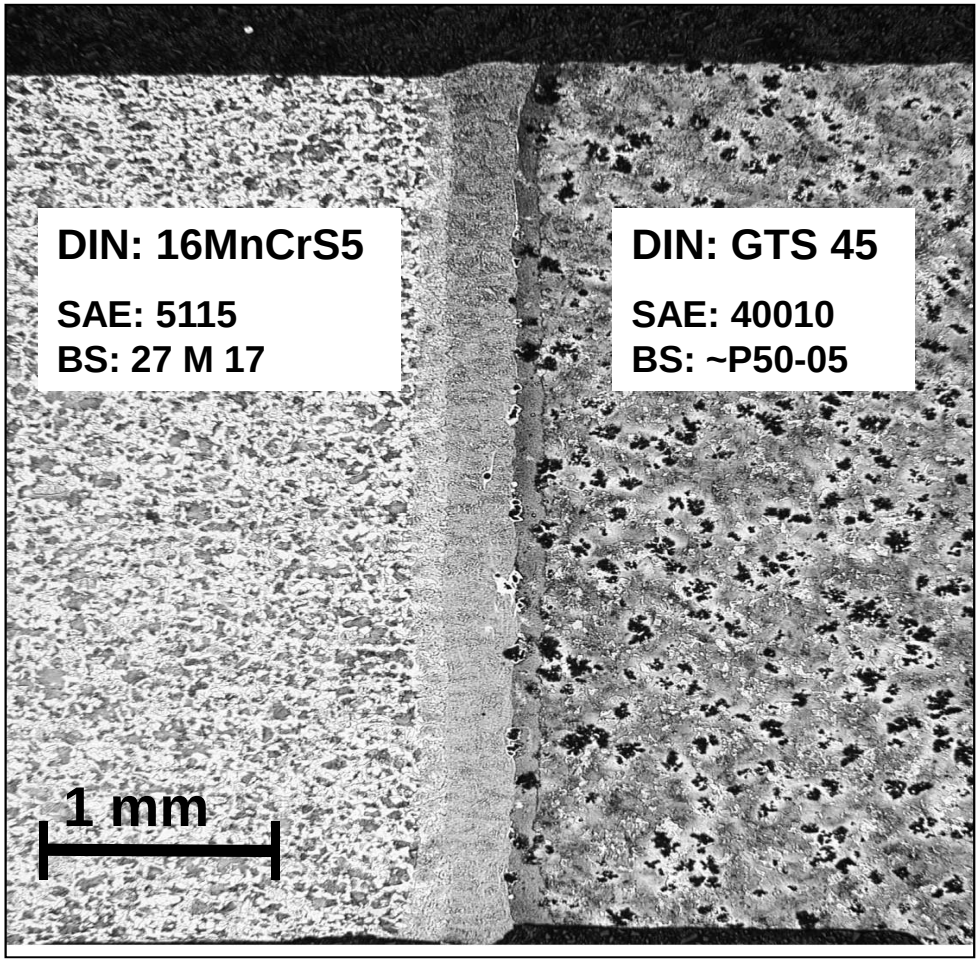
fiber laser
4.0 kW
v_S = 4.5 m/min
without filler wire
welding time: 6 s



Laser beam welding with fiber laser

P_L = 4 kW
Fiber Ø = 50 µm
2 mm mrad

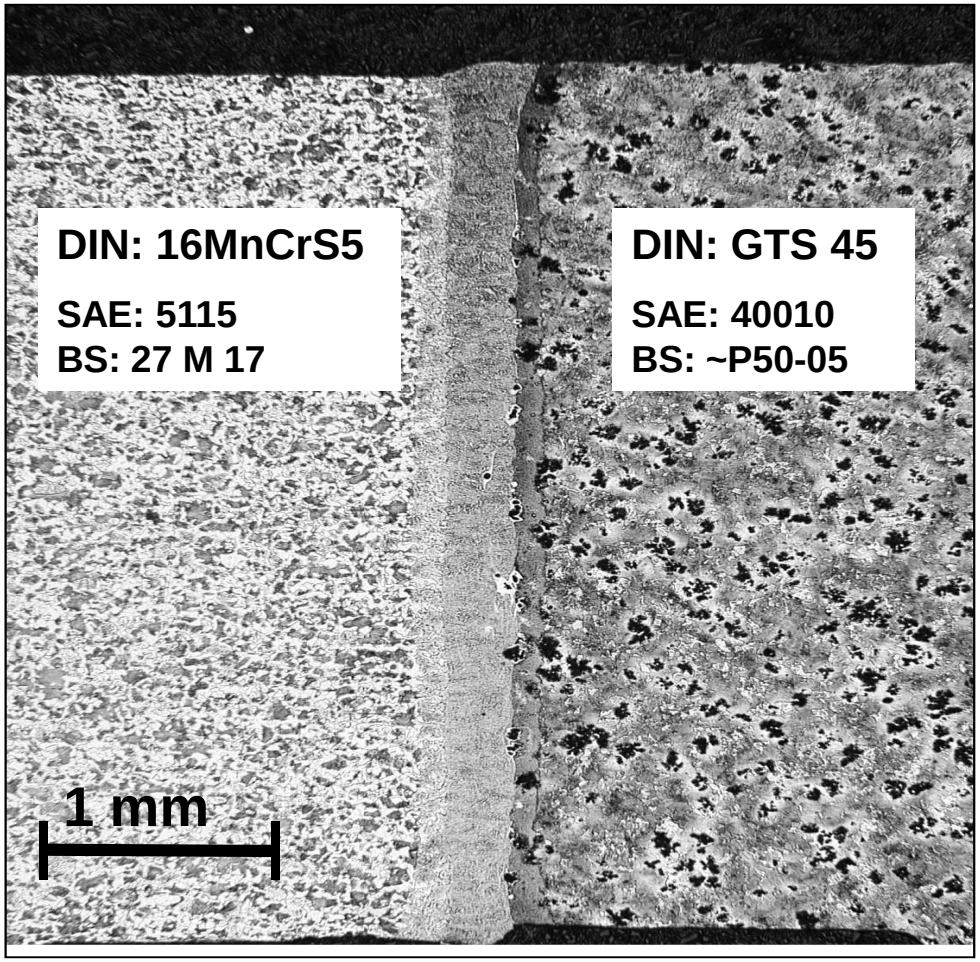




Laser beam welding with fiber laser

P_L = 4 kW
Fiber Ø = 50 µm
2 mm mrad

P_L = 6 kW
CO2 Laser. Filler Wire



Integration of single cells to complete batteries

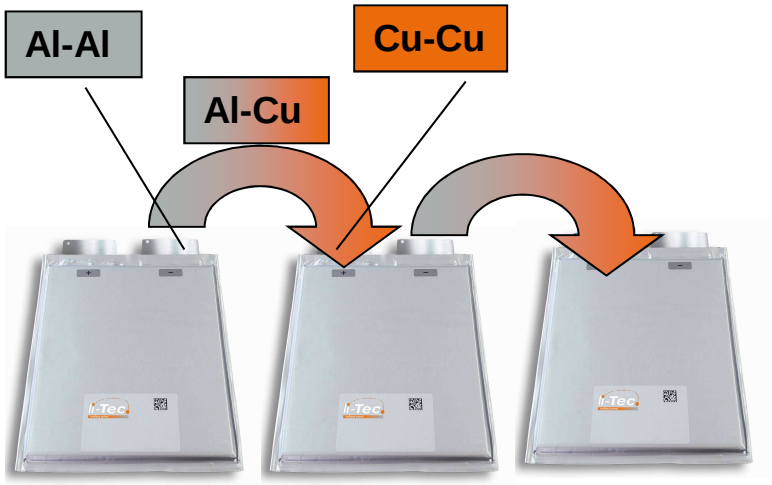
- Series connection single cells to high voltage batteries, that’s means connection between Al- and Cu-electrodes

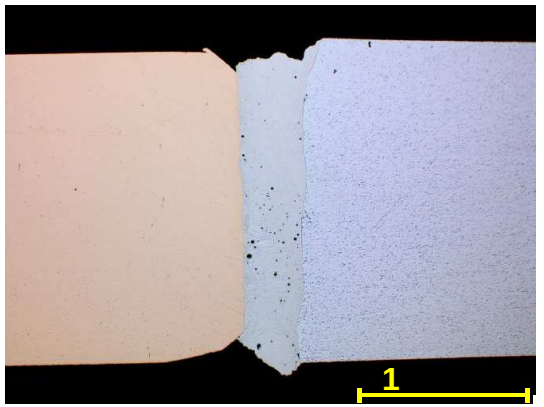
- Long life stable connections for automotive battery systems require
  - low electrical transition resistance
  - sufficient mechanical stability (static strength, fatigue strength
  - no thermal or electrical degradation (Al/Cu)

©Li-Tec Battery GmbH

Copper – Aluminium – Cell Connector

- Development of laser weldable Al-Cu-transition joints with low electrical transition resistance by
  - laser beam welding with high speed scanning
  - friction stir welding
  - laser induction roll cladding





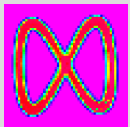
center

Laser beam welding with high-frequency beam oscillation

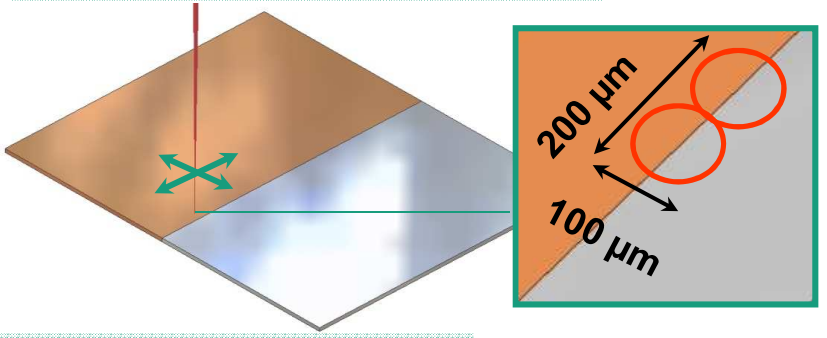
Copper to Aluminium

Parameter:

- Laser Power 1500W
- Welding speed 4 m/min
- Scan frequency 2000 Hz
- Scan width 100 µm
- Scan length 200 µm

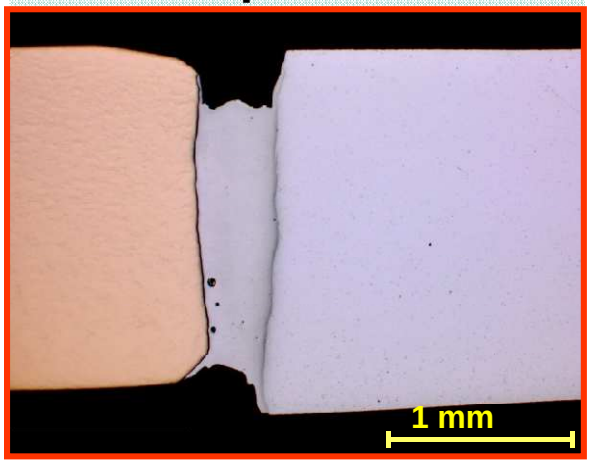


2-dimensional Scanning

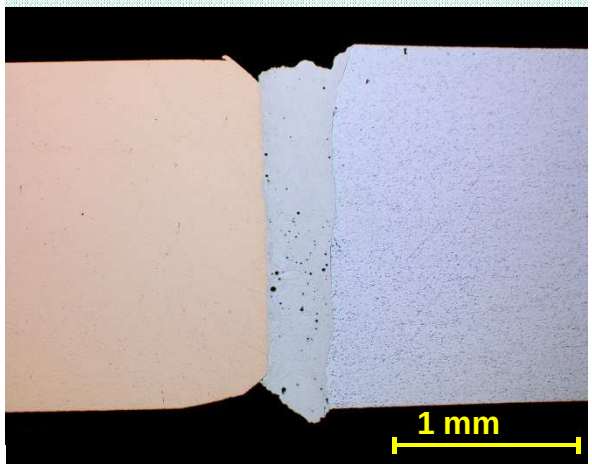


lateral beam displacement

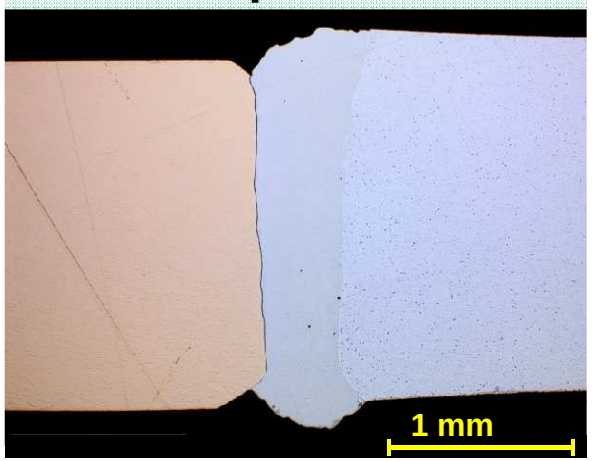
100 µm to Cu



center



100 µm to Al



increasing Al-Vaporization as a result of the lateral beam displacement to Copper

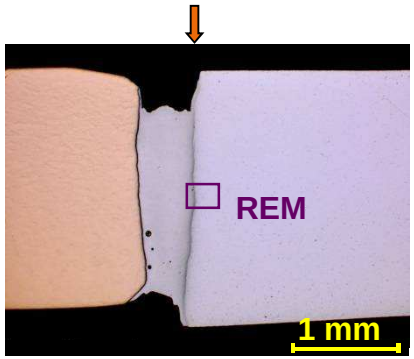
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Fraunhofer IWS Dresden

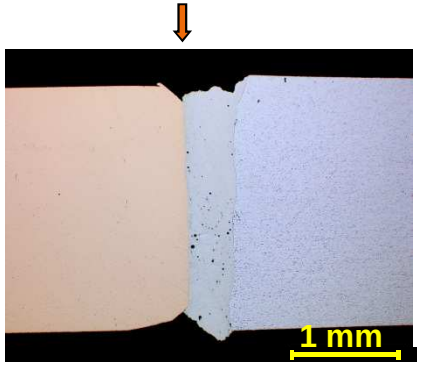
Laser beam welding with high-frequency beam oscillation

Copper to Aluminium

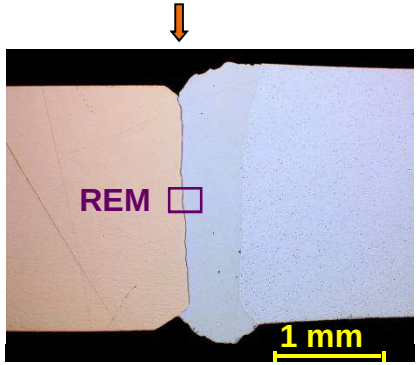
Fracture position



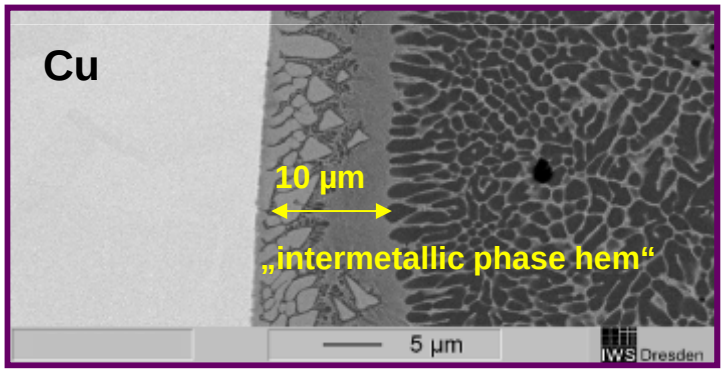
100 µm to Al

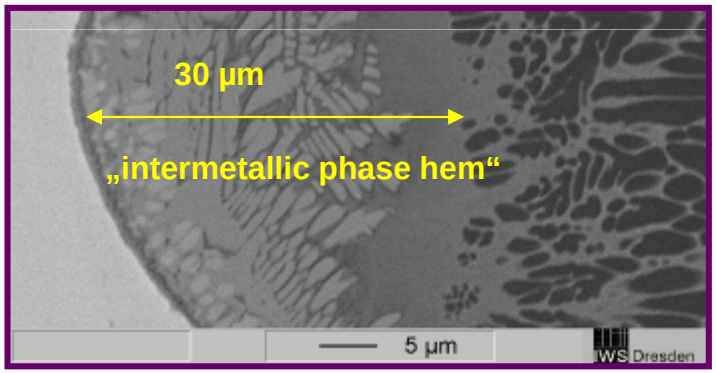


center



100 µm to Cu



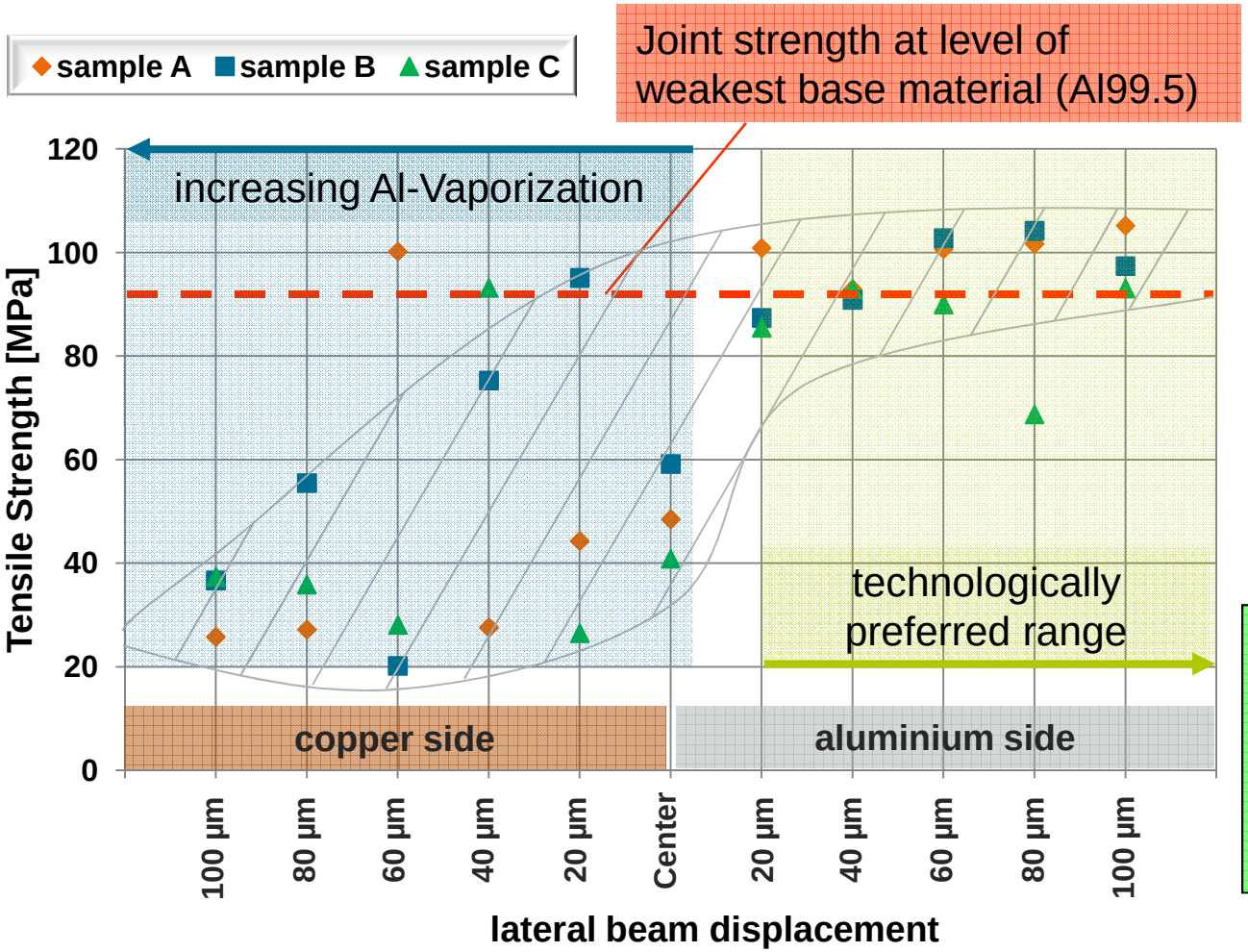


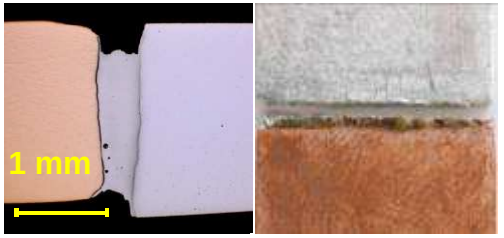
Increasing IM phase hem width on the fusion line to Al, by beam displacement to Cu leads to reduced strength

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Laser beam welding with high-frequency beam oscillation

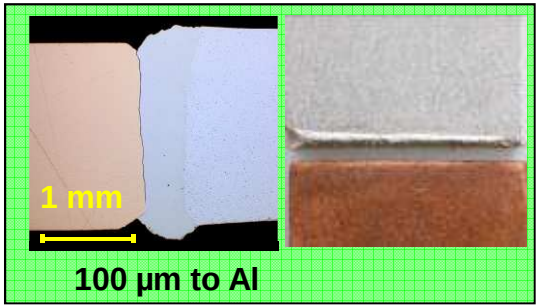
Copper to Aluminium





100 µm to Cu

center

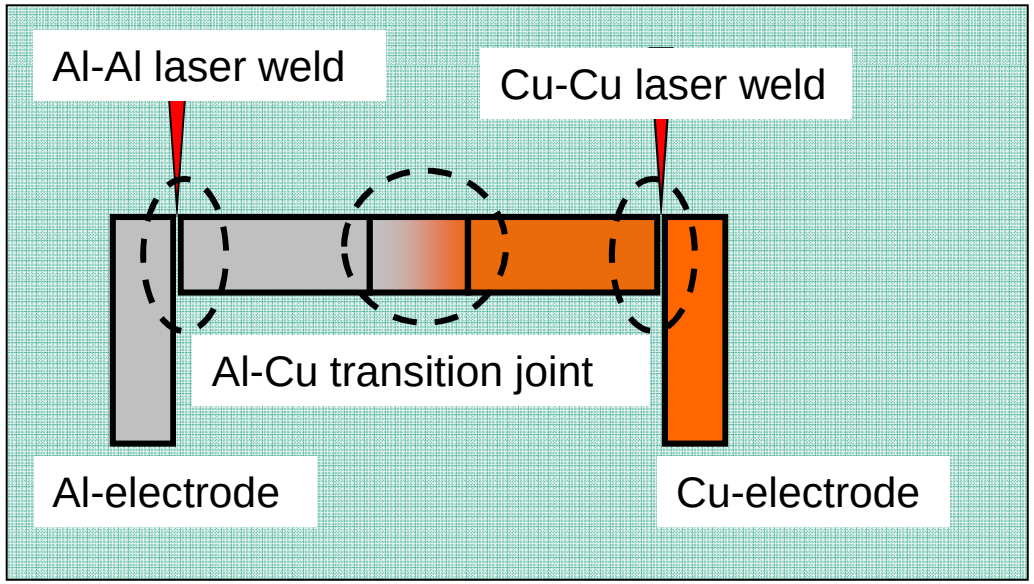


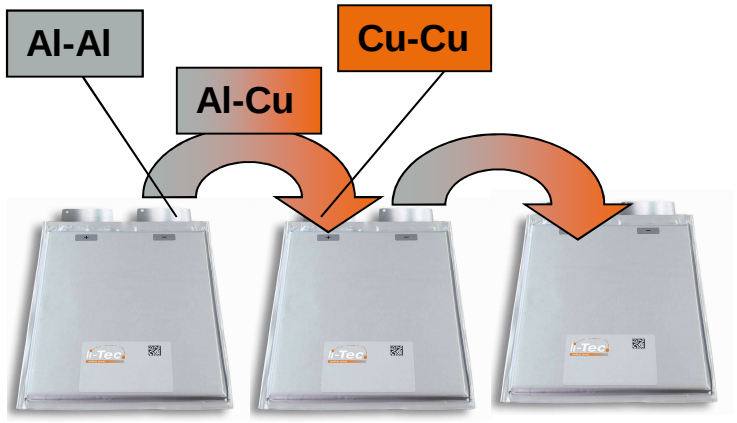
100 µm to Al

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Copper – Aluminium – Cell Connector

- Development of laser weldable Al-Cu-transition joints with low electrical transition resistance by
  - laser beam welding with high speed scanning
  - friction stir welding
  - laser induction roll cladding





Remote welding with large working area

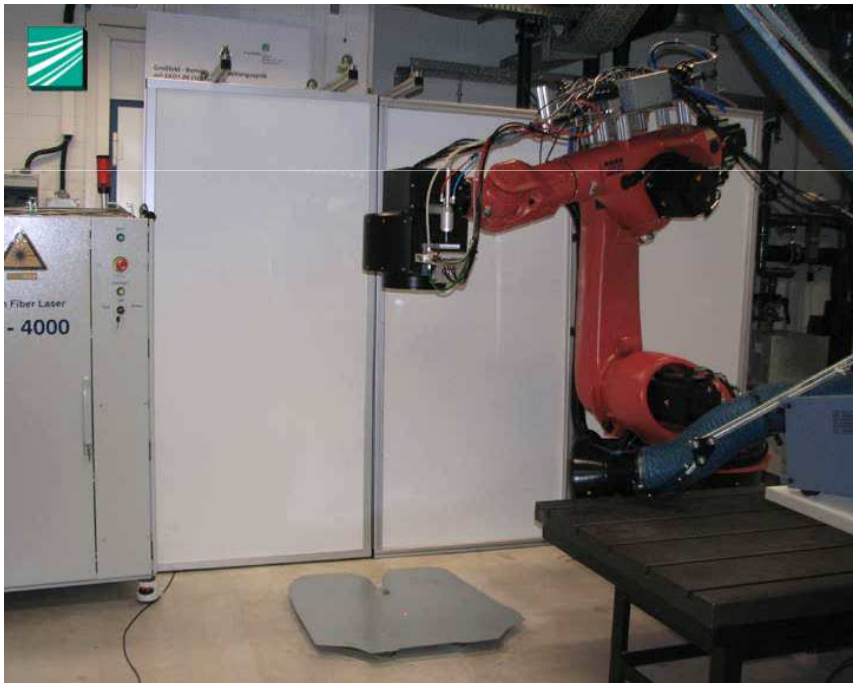
High power Remote laser beam welding at large working areas

- Compact design (0.65 x 0.45 x 0.3 m^3)
- Low weight (35 kg)
- Working field of 2 x 2 m^2
  at working distance of 2.0 m
- Dynamic behaviour:
  - Positioning speed 10 m/s
  - Reproducibility 0.175 mm
- Optical parameter:
  - Optical scaling 1:10 for focal length 2 m
  - Z-axis +/- 250 mm

Remote welding with large working area

High power Remote laser beam welding at large working areas

- Compact design (0.65 x 0.45 x 0.3 m^3)
- Low weight (35 kg)
- Working field of 2 x 2 m^2
  at working distance of 2.0 m
- Dynamic behaviour:
  - Positioning speed 10 m/s
  - Reproducibility 0.175 mm
- Optical parameter:
  - Optical scaling 1:10 for focal length 2 m
  - Z-axis +/- 250 mm



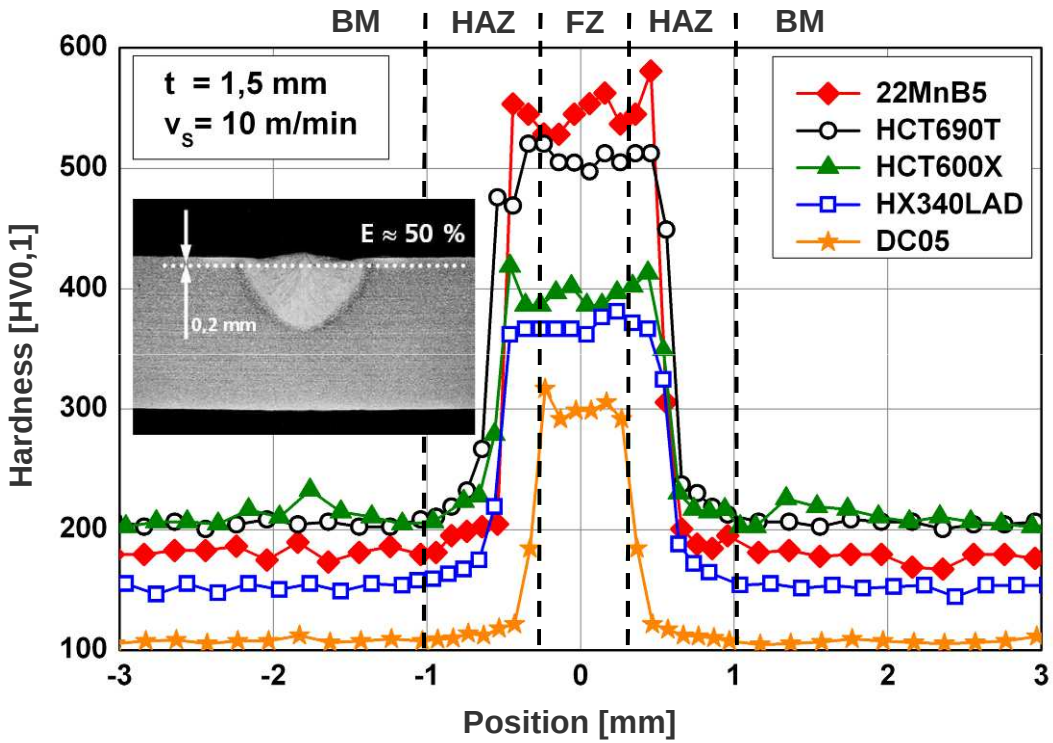
Hardening Behaviour – Hardness Distribution

Characterization:

Significant hardening for all steel grades

Constant hardness level in hardened zone

Hardness values correlate with C-content



FZ: Fusion zone
HAZ: Heat affected zone
BM: Base material

Fraunhofer IWS Dresden

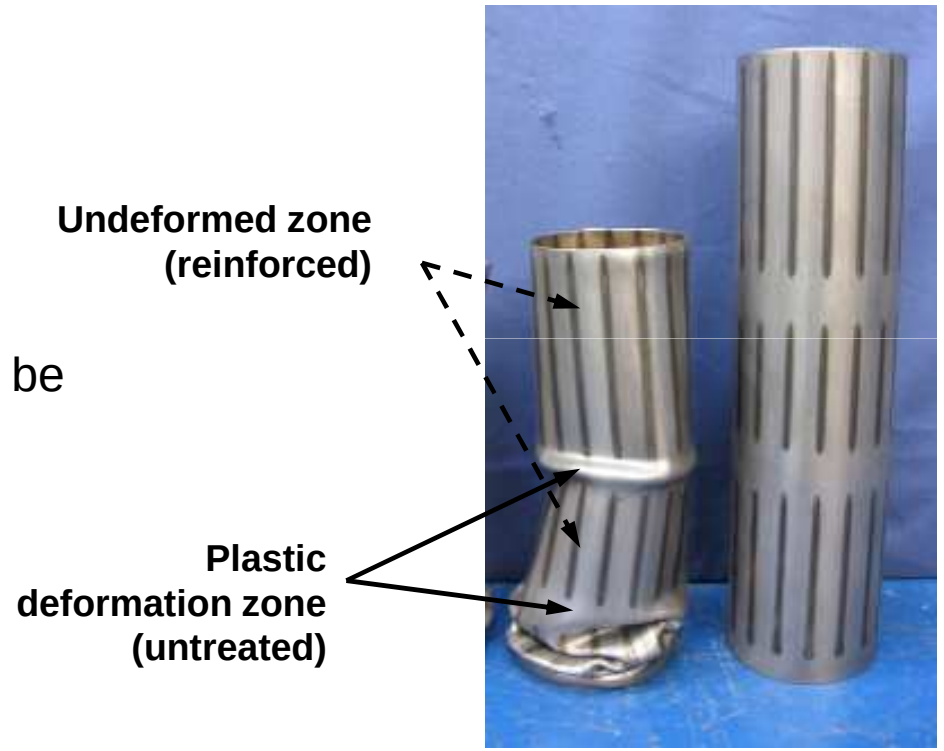
Compression Crash Test – Results

Deformation mode:

Definition of deformation areas

Local prevention of plastic deformation

Deformation behaviour can be controlled



Bending Crash Test

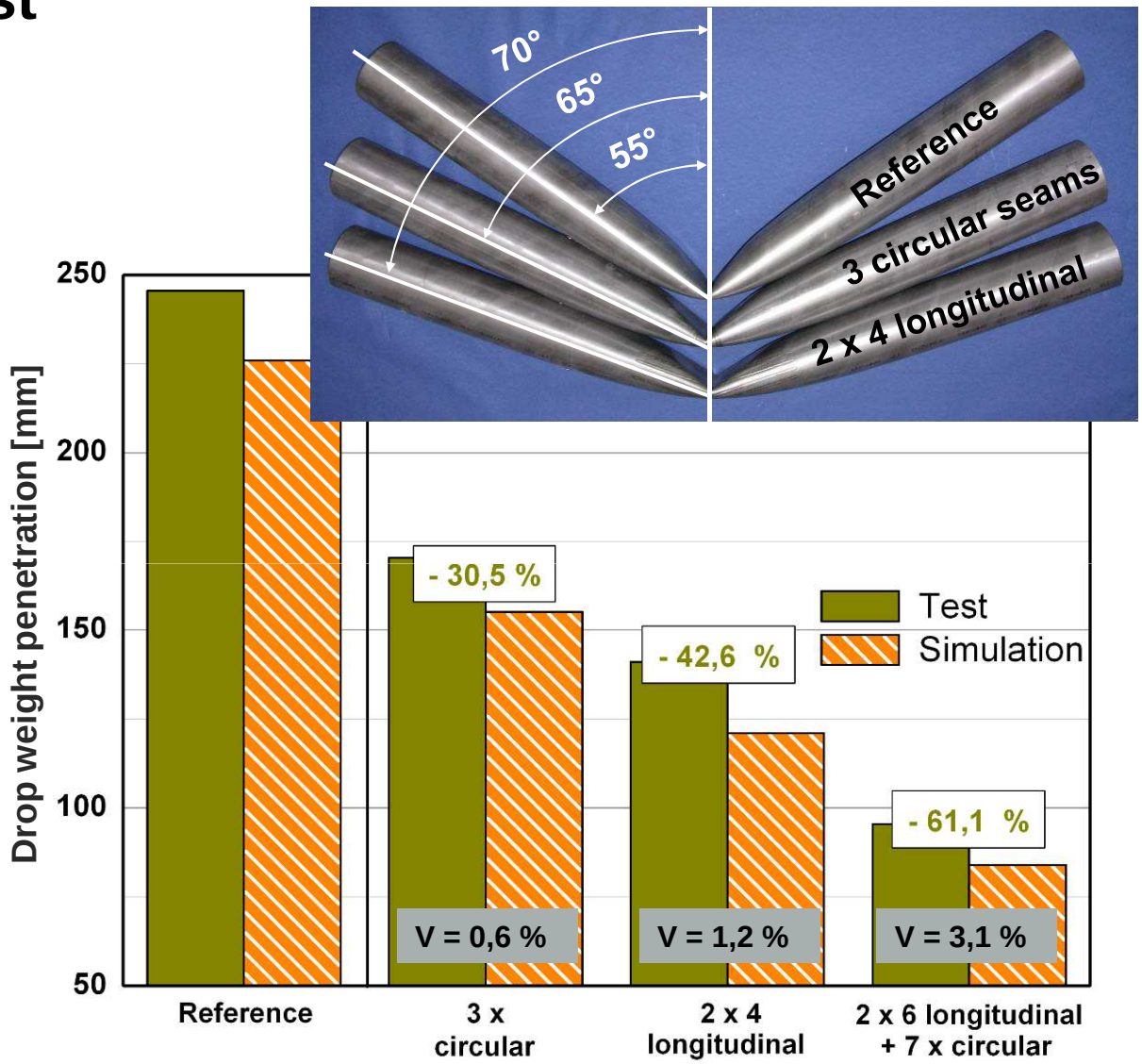
Without reinforcements

V = 3,1 % reinforcement
(7 circular + 2 x 6 longitudinal seams)

Bending Crash Test

Results:

- Clear reduction of deformation
- Strong increase of energy absorption
- Correlation to volume of hardened material
- Relatively low hardening volume necessary

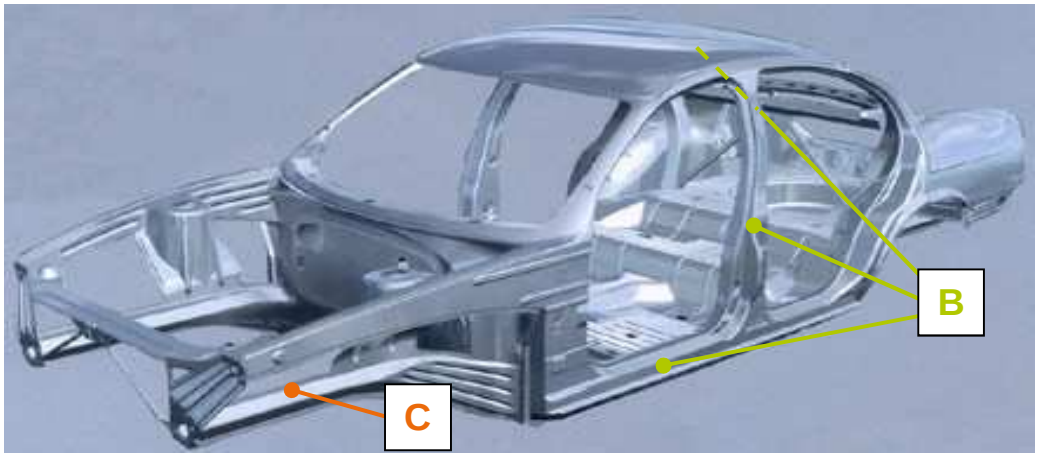


Application Examples

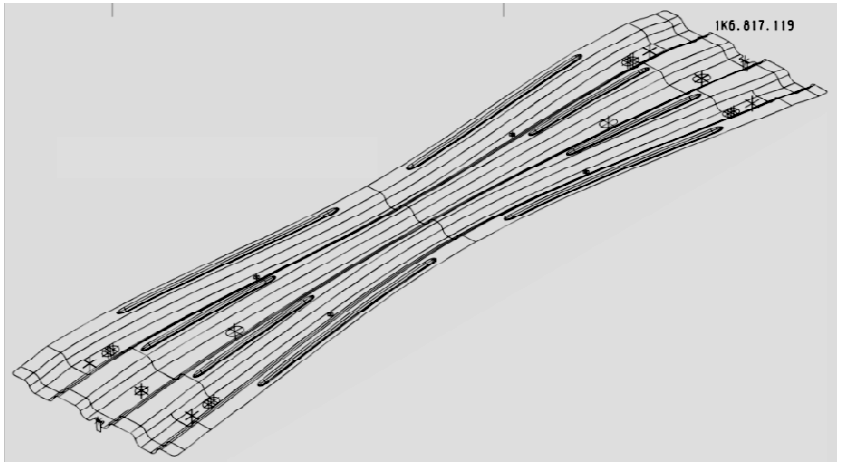
Crash components:

Compression load [C]

Bending load [B]

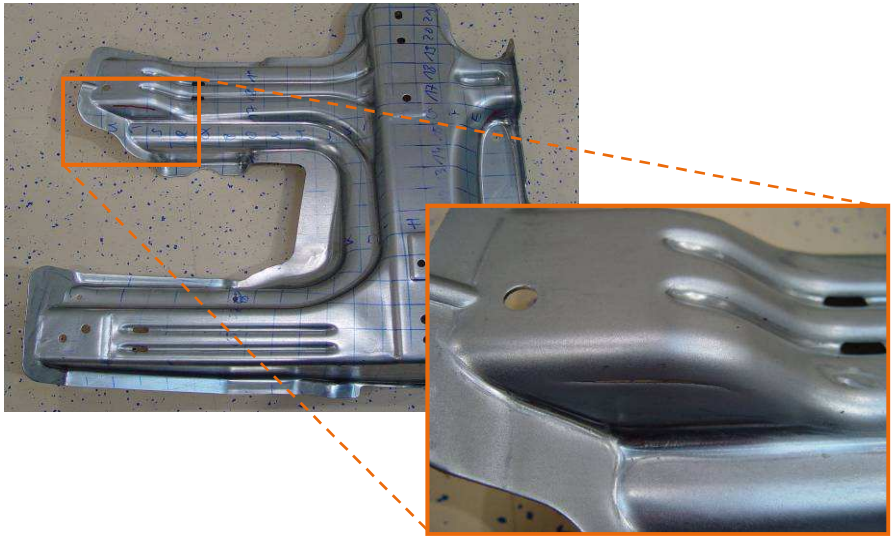


Load adapted component design



Deep drawing parts:

- Enhancement of formability

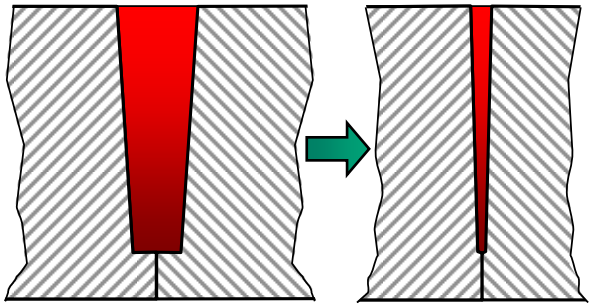


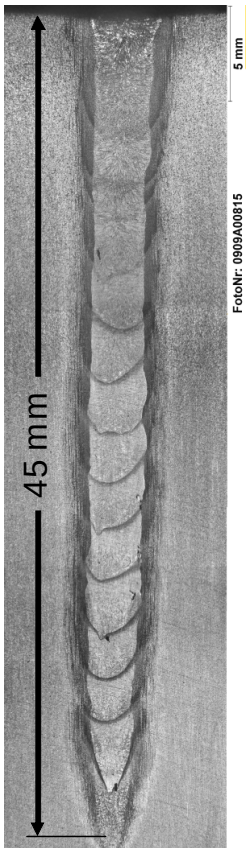
Narrow gap multi seam welding

High Beam Quality offers New Possibilities

Goals:

- Welding of thick sections (> 10 mm)
- Low distortion
- Low heat input
- High productivity
- High weld quality
- Easy on-site application





Narrow gap multi seam welding

State of the Art for Narrow Gap Welding / Thick Section Welding:

Process

Conventional welding

- MIG, MAG
- Keyhole plasma welding
- Electro-slag welding

} Cheap but large welds with high heat input

Beam welding

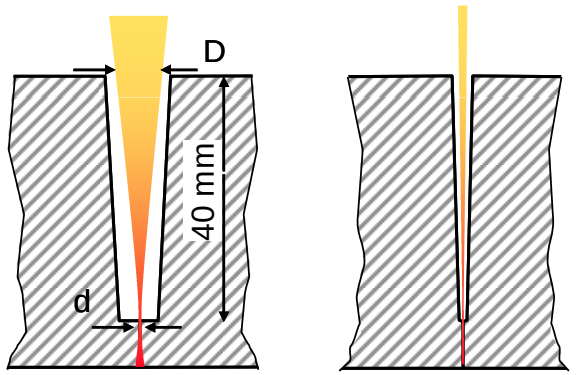
- Electron Beam — Fast, deep penetration, complicated (vacuum, demagnetization)
- very-high power lasers (>10 kW) — Simple, expensive, limited applicability
- Multi-pass welding (CO_2, Nd:YAG) — Thin, long gaps possible (limited by caustic)
- Hybrid welding — Efficient, complicated setup, limited depth

Narrow gap multi seam welding

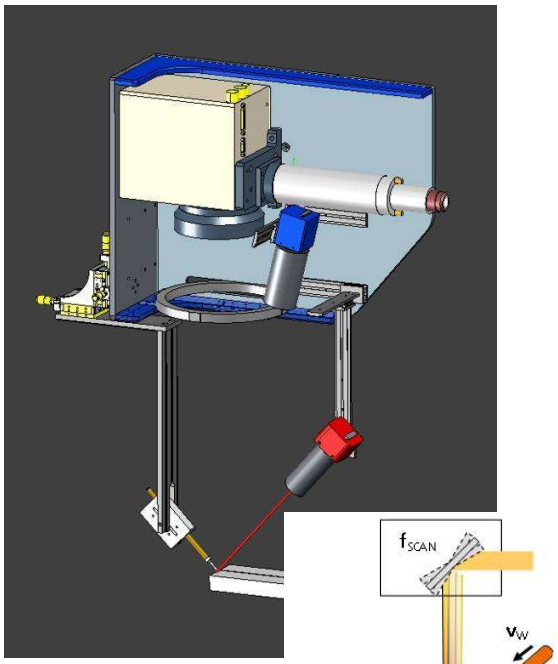
Using Fiber Lasers to Improve Multi-Pass Laser Welding

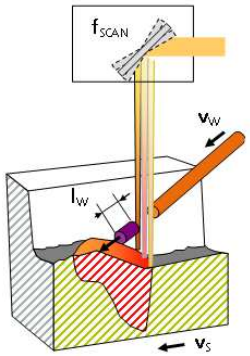
Enhancements due to increased Beam Quality
(reduced beam divergence):

- Focal position setup simple (marginal power density changes along depth)
- groove angle can be reduced
- Filler wire is guided horizontally in narrow groove
- Amount of filler material reduced in narrow groove
- High total intensity reduces reflection problems on filler wire



Narrow gap multi seam welding



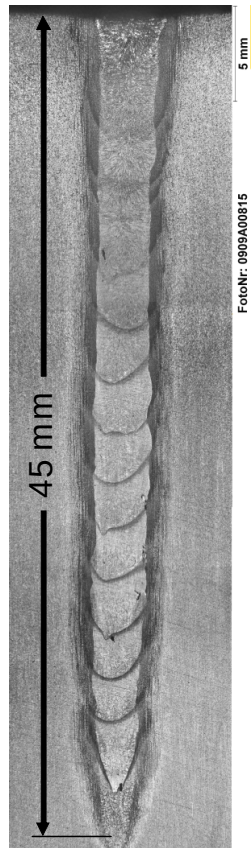


Laser

Laser & Filler wire

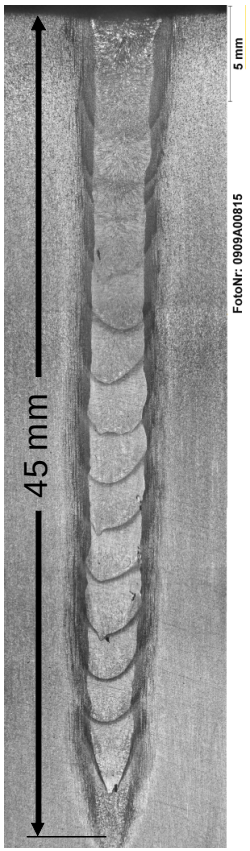
Root seam

Multi seam

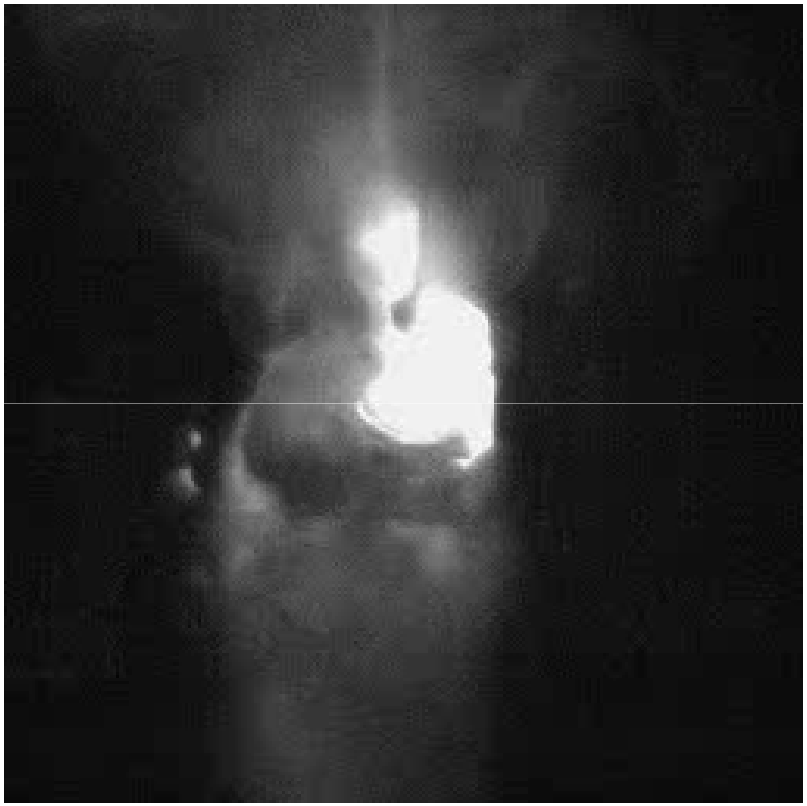


Narrow gap multi seam welding

High strength steel up to 50 mm
e. g. for cranes, wind power,..



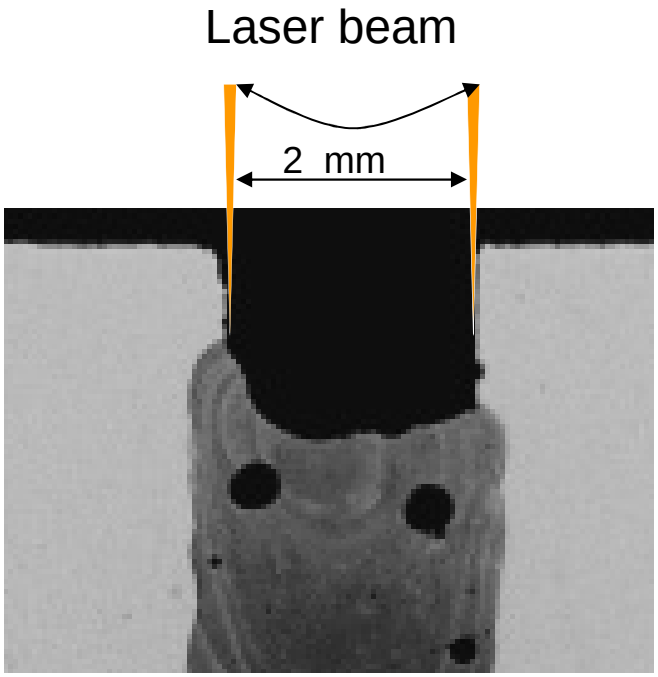
Source: www.schwaebische.de/cms_media

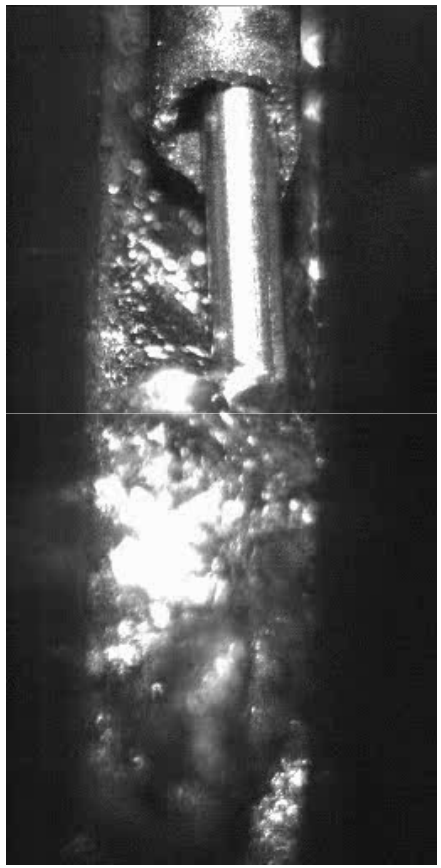


High speed process video

Narrow gap multi seam welding

Crack sensitive Aluminium alloys up to 50 mm





High speed process video

Summary

Beam quality of brilliant lasers offers a wide range of applications

- Quality and reliability of high brightness lasers have been improved essentially

- Keyhole can be specifically formed through the high-frequency oscillation of the beam and used for:
  - Improved process stability with reduced amount of weld spatters and pores
  - Welding of different materials as for example the combination of aluminium and copper or cast iron and steel

- New possibilities for remote welding with large working field

Many thanks for your attention.