AVOIDANCE OF END CRATER IMPERFECTIONS AT HIGH-POWER LASER BEAM WELDING OF CLOSED CIRCUMFERENTIAL WELDS

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Motivation – Circumferential Welds

Pipeline construction

Wind turbine towers

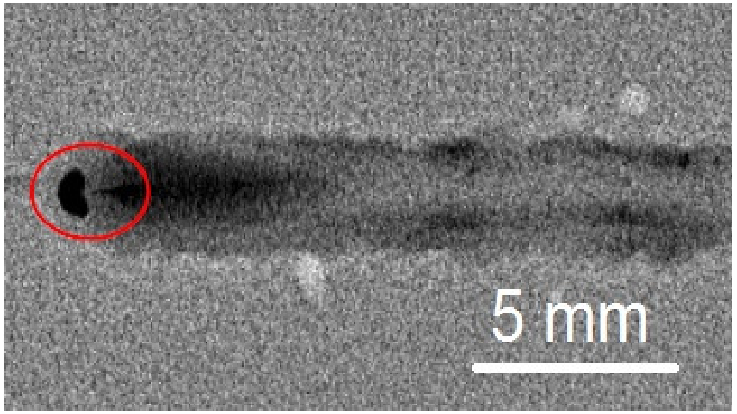
Hydraulic cylinder

Tank and apparatus construction

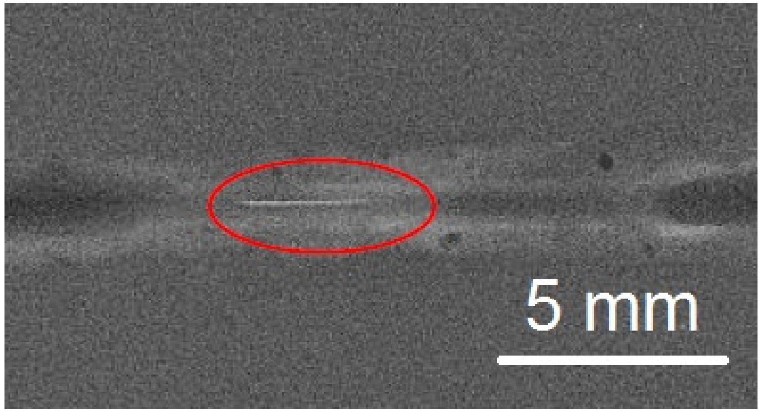
Challenges of circumferential laser beam welds

The problem with closing circumferential laser beam (LBW) or hybrid laser arc (HLAW) welds is the formation of end crater defects in a overlap area

Overlap area of a LBW pipe of grade X70 with a wall thickness of 8 mm



End crater hole and shrinkage cavity at abrupt switch-off of the laser beam power



Cracks in the overlap at laser power ramp

- End crater holes can be avoided with a laser power ramp, however cracks are formed in the material thickness

Research project

„Method for defect-free hybrid laser arc welding of closed circumferential welds“

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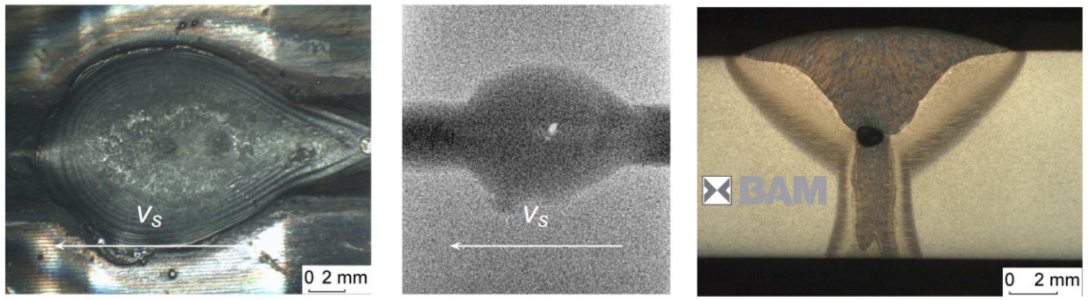
<u>Goals of the project</u>

- Achieving a defect-free overlap of circumferential hybrid laser arc weld by adapting LB and GMA welding process parameters;
- Development of a method that can significantly expand the application field of laser hybrid technology

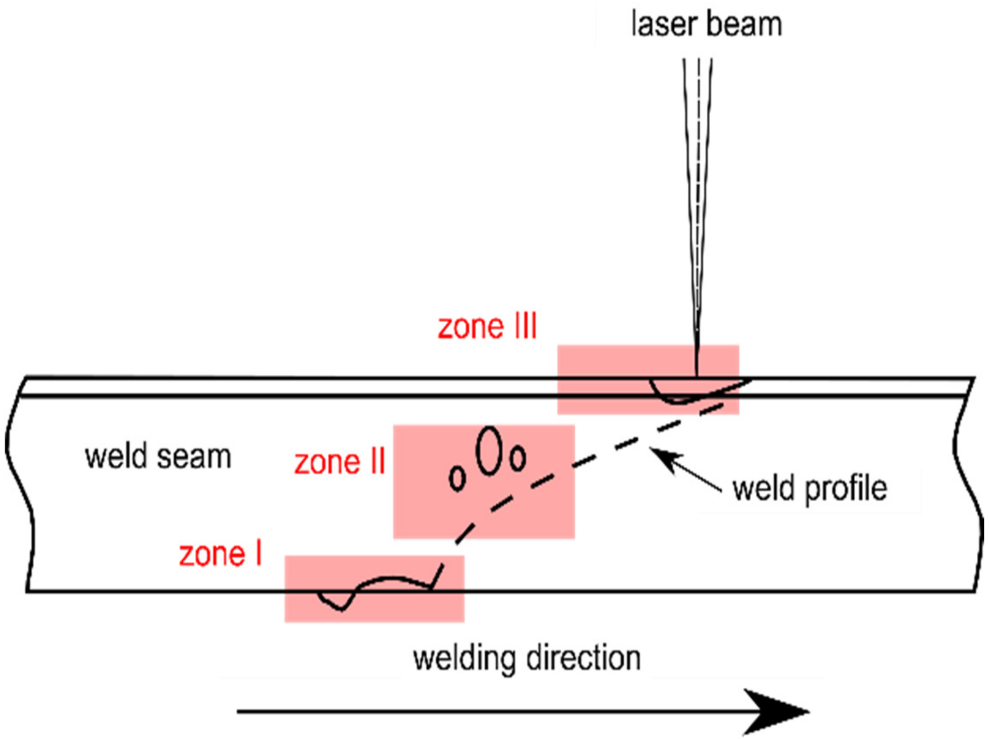
there are none yet universal solutions for defect-free execution of overlap areas closed circumferential LBW and HLAW welds in the thick sheet metal sector



Pore in overlap area of a circumferential weld, HLAW of pipe segment with 9 mm thickness

Results of the AiF project “Hybrid laser-GMA welding of thick-walled precision tubes" (BAM)

Localisation of the imperfections



Zone I Defects on the root side:
Root excess weld metal / shrinkage groove

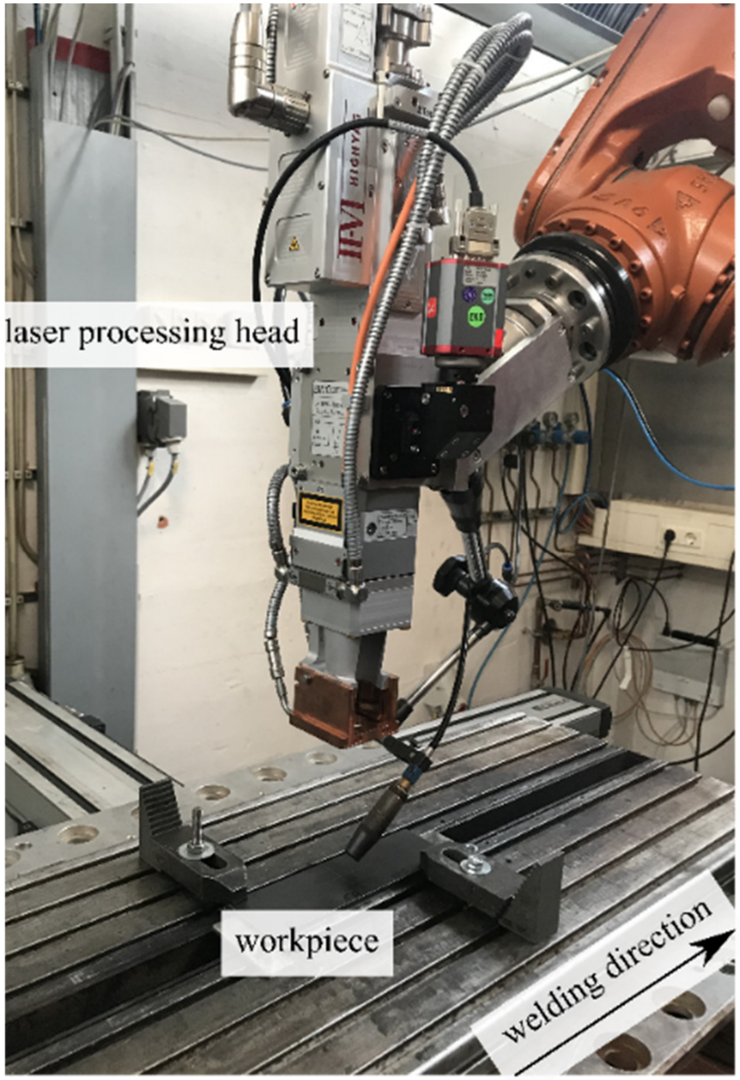
Zone II Defects in the mid-thickness:
Cracks and pores

Zone III Defects on the top side:
End crater with shrinkage cavity

- Defects are distributed in the length of the overlap as well as over the material thickness
- Avoidance of the imperfections needs a complex strategy of heat transfer in the overlap

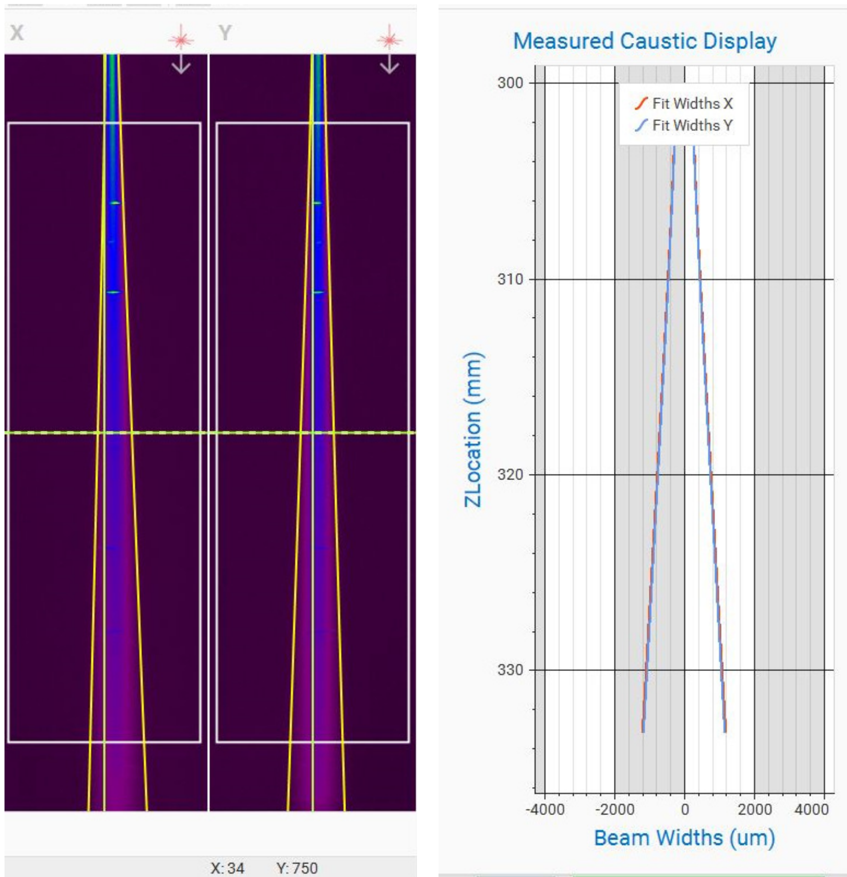
Experimental Setup

- High-power Yb:YAG disk laser TruDisk 16002
- Laser processing head BIMO with a MZ-collimator
  - Adjustment range of the focal position in Z-direction: -10 mm / +30 mm (optional +80 mm)
  - Magnification M: 2.5 – 6
  - Focus diameter at 200 µm optical fiber: 500 µm - 1200 µm
- Materials used for this study:
  - Flat specimens of S355J2 with a thickness of 10 mm
  - Pipes of X100Q (WT of 9.5 mm, outer diameter of 5 inches)

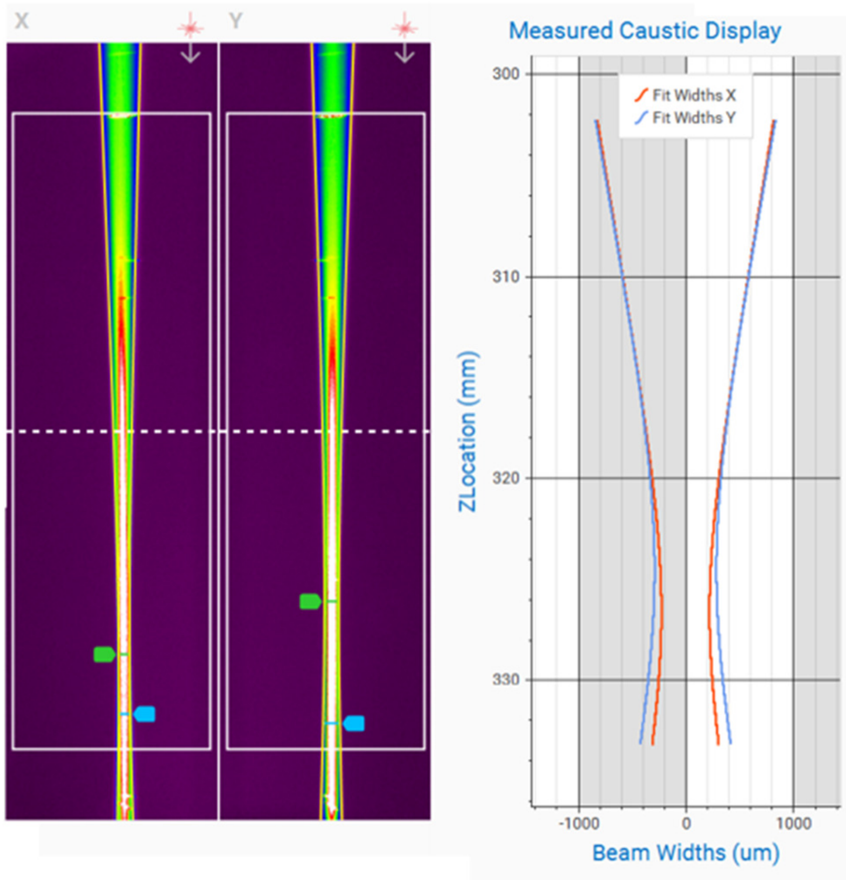


Beam profile measurements – Variation of Z

- Beam profile measurements were taken with an Ophir Spiricon BeamWatch non-contact laser measurement device at 2 kW laser power

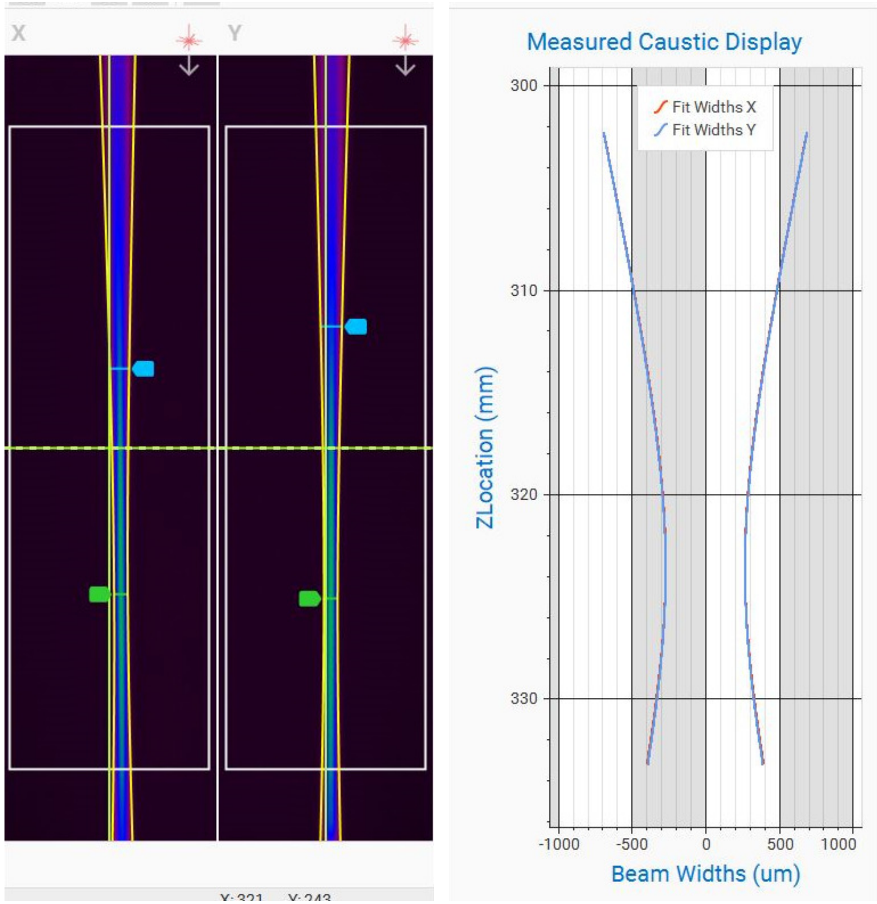


Z = 0 mm; M = 2.8; $\varnothing_{fz0}$ = 560 µm

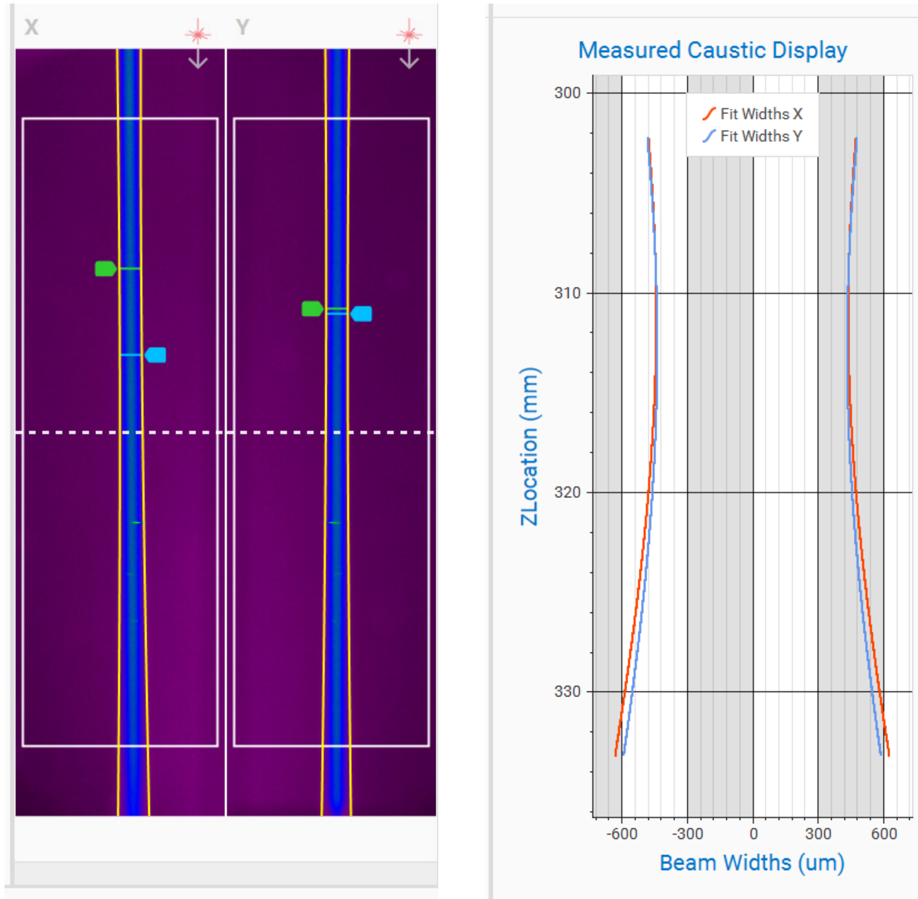


Z = 30 mm; M = 2.8; $\varnothing_{fz30}$ = 2100 µm

Beam profile measurements – Variation of M

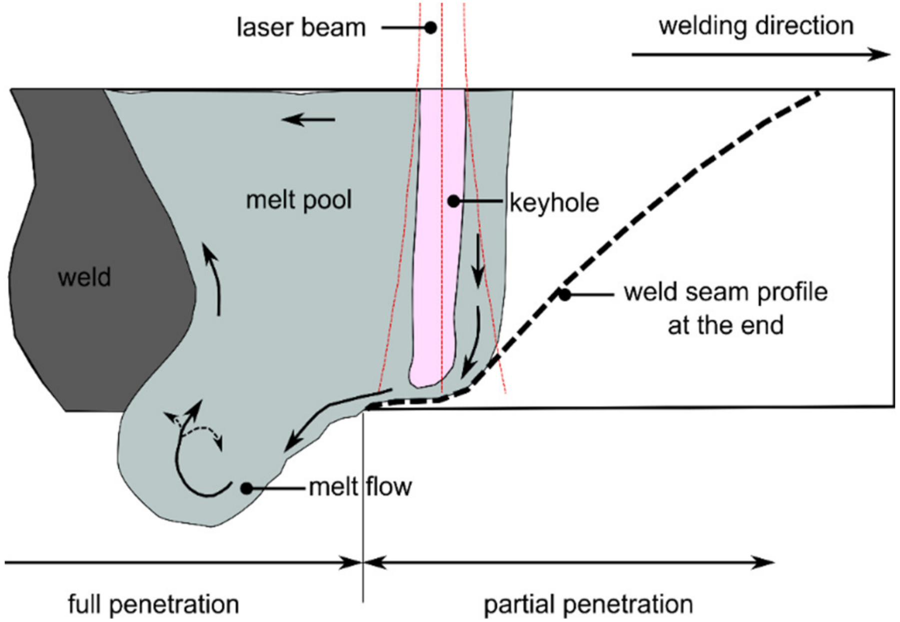


Z = fixed; **M = 2.8**; $\varnothing_{fz0}$ = 560 µm

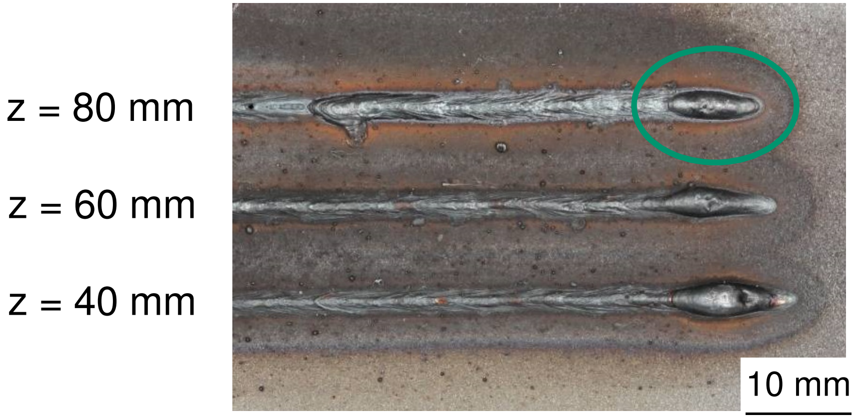


Z = 30 mm; **M = 5.8**; $\varnothing_{fz30}$ = 1160 µm

Results – Zone I (root defects)



P_L = 10 kW, v_w = 1.0 m min^{-1}, t = 10 mm



outfeed length = 15 mm

outfeed length = 30 mm

- higher defocusing >40 mm with a shorter outfeed length is preferable
  → smooth transition from full penetration to partial penetration with root quality according to EN ISO 12932 valuation class B

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Results – Zone II (defects in the mid-thickness)

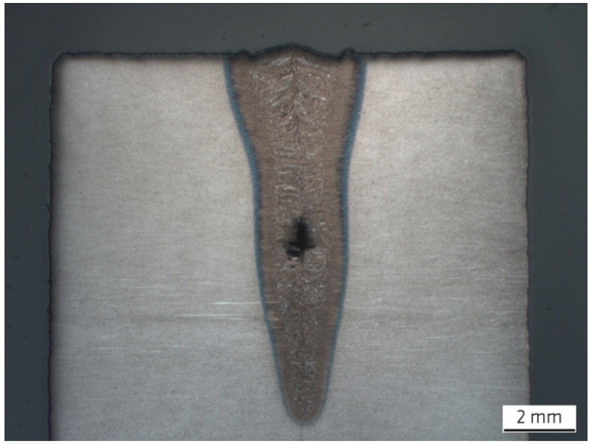
Solidification cracking

Characteristics

- Occur at temperatures higher than the solidus in the late stages of solidification
- Involves the separation of grains or dendrites

Possible mechanical causes (stresses)

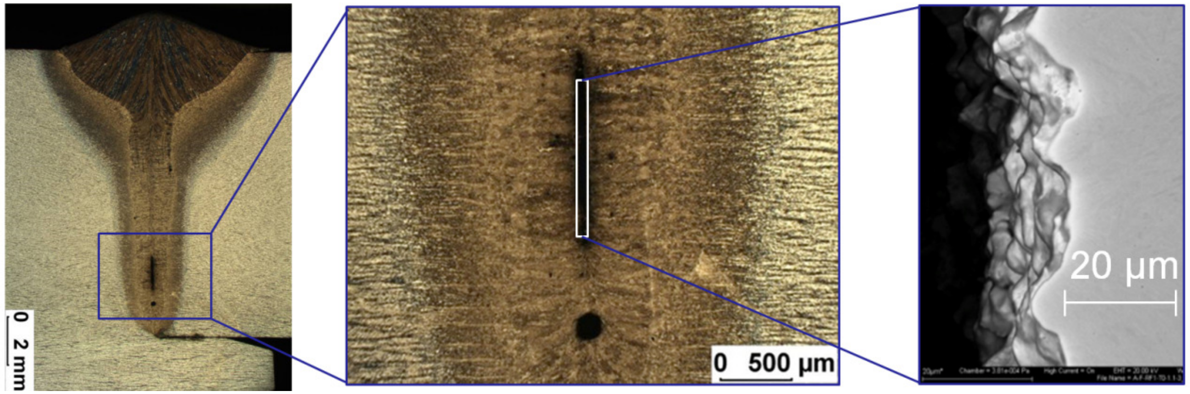
- Interdendritic pressure drop (forms a cavity) and aditional tensile stresses
- Tensile stresses exceed the fracture stress of liquid film
- The partial penetrated LBW or HLAW welds are primarily prone to center line solidification cracking than fully penetrated welds



Centreline solidification crack by laser beam welding

V = 2 m min^{-1}
P_l =10 kW
Z_f = -3 mm
Material S355

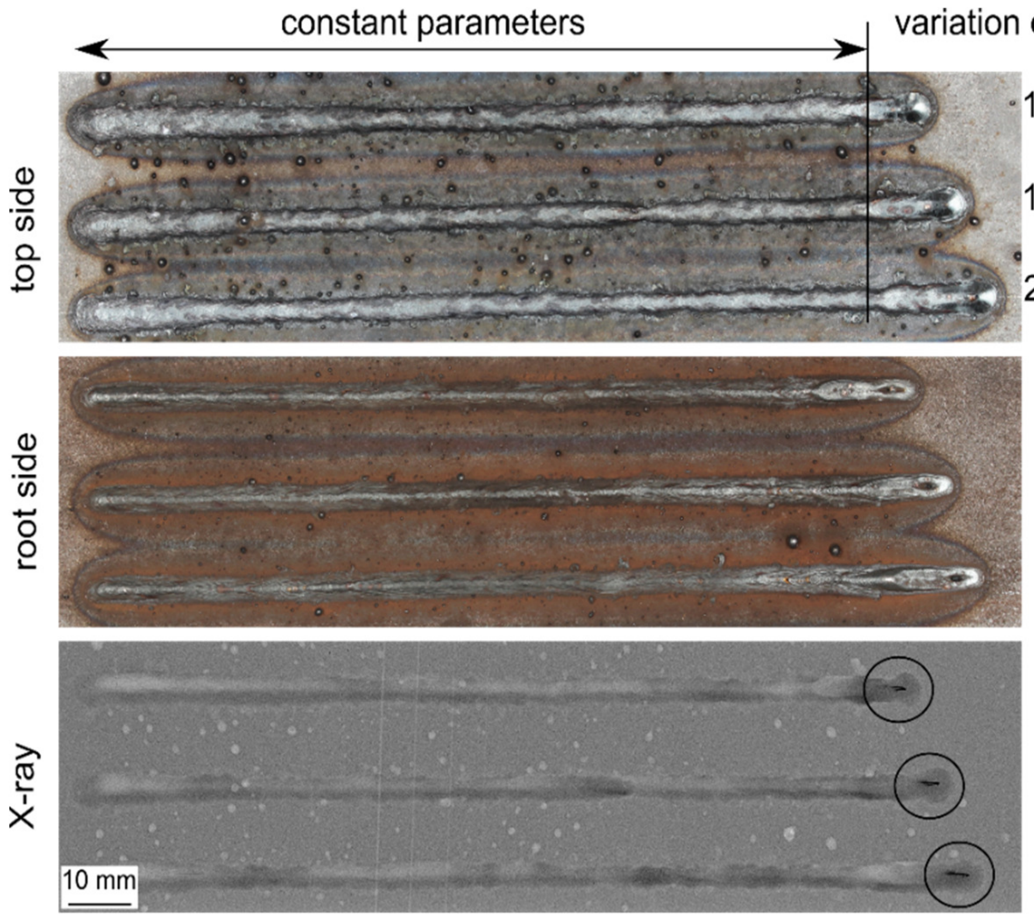
Centerline crack in a hybrid laser arc weld



Gebhardt, 2013

Results – Zone II (defects in the mid-thickness)

- Variation of the **magnification M 2.8 – M 5.8**



P_L = 10 kW, v_w = 1.0 m min^{-1}, t = 10 mm

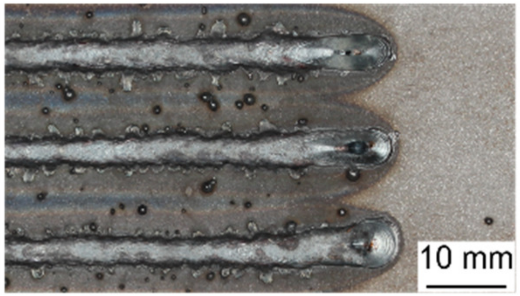
- Too high energy density also at the highest magnification M 5.8, fØ = 1160 µm

- End crater hole is formed over the entire seam thickness

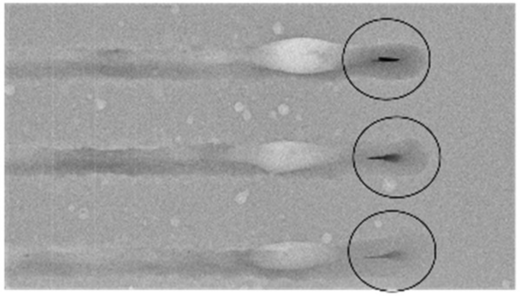
Results – Zone II (defects in the mid-thickness)

- Variation of the **focal position in Z-direction**

top side



X-ray

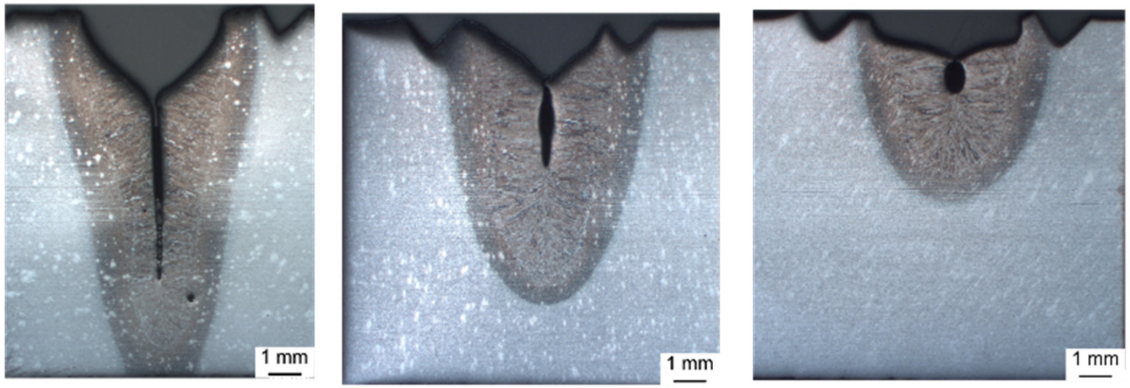


defocusing

40 mm
(fØ = 2.9 mm)

60 mm
(fØ = 4.3 mm)

80 mm
(fØ = 5.6 mm)



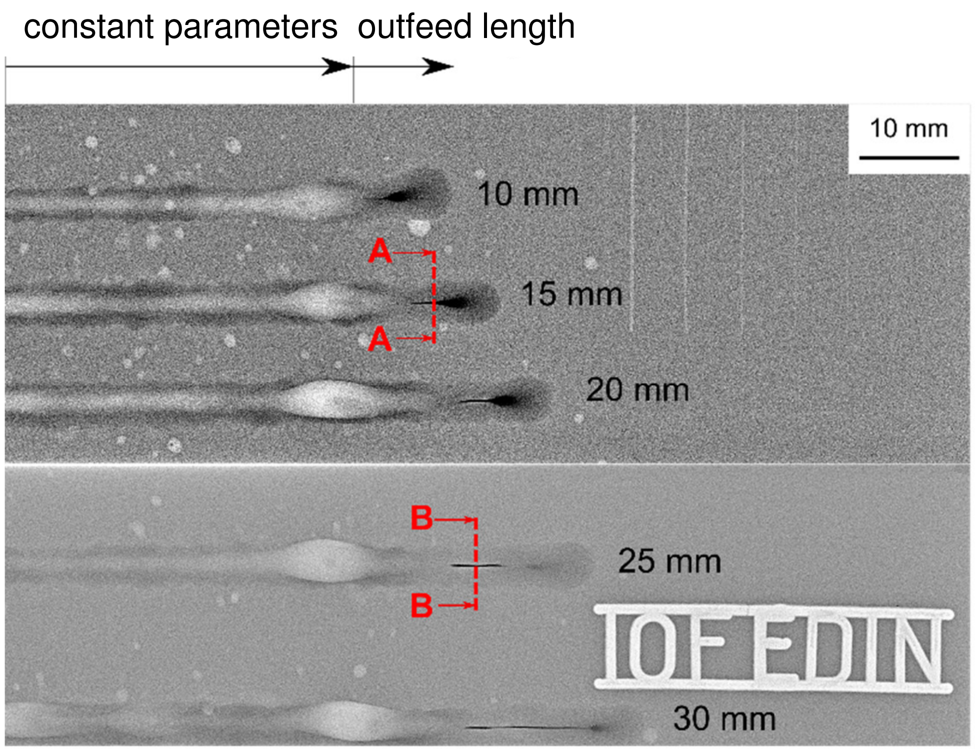
40 mm　　60 mm　　80 mm

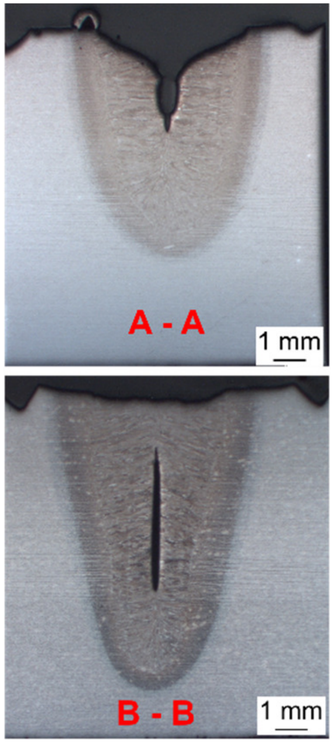
P_L = 10 kW, v_w = 1.0 m min^{-1}, t = 10 mm

- Highest impact on the weld shape formation was found with a high defocusing
- Smooth transition could be reached at a defocusing over 80 mm
- Shrinkage cavity on the top surface

Results – Zone II (defects in the mid-thickness)

- Variation of the **outfeed length**





- Increase of crack length with increasing outfeed length
- Increase of drop size with increasing outfeed length
- Cracks are formed in the partial penetrated part of the LBW
- Outfeed length of 10 mm to 15 mm lead to best results

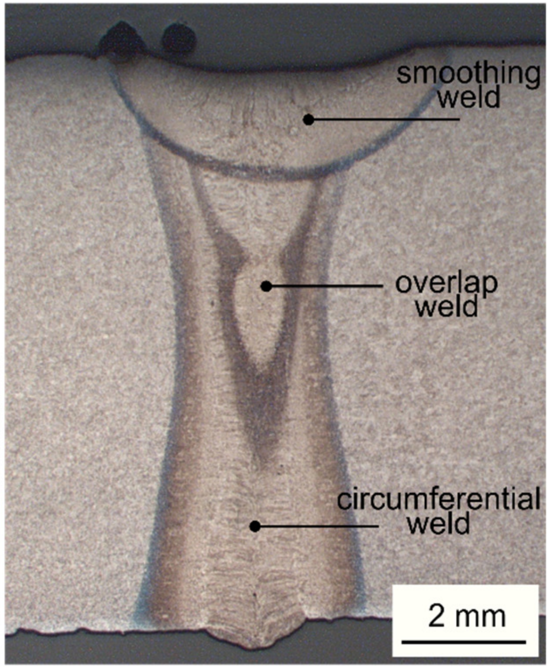
P_L = 10 kW, v_w = 1.0 m min^{-1}, t = 10 mm, defocusing 80 mm, M 2.8

Results – Zone III (defects on the top surface)

Transfer of results to circumferential welds

- End crater shrinkage cavity on the top surface could be avoided with smoothing weld using 2 kW laser beam power and an defocussed laser beam with a focus of 4.3 mm on the top surface at a welding speed of 0.5 m min^{-1}

P_L = 11.5 kW,
v_w = 1.0 m min^{-1},
t = 9.5 mm,
defocusing z 80 mm,
M 2.8,
outfeed length 15 mm



Conclusions

- Formation of the end crater imperfections at LBW of closed circumferential welds could be effectively minimized by the adjustment of the process parameters such as defocusing of the laser beam;
- Defocusing of >40 mm is recommended with regard to minimizing of root drop size at the end of the weld seam;
- Increase of the crack length with increasing overlap length → short outfeed length of 10 mm to 15 mm is recommended;
- Cracks and pores in the mid-thickness could be eliminated at a defocusing of the laser beam 80 mm → shrinkage cavity shifts to the weld top surface
- Shrinkage cavity on the weld top surface could be avoided with a smoothing weld using a low power of 2 kW at a spot diameter of 4.3 mm
- Transfer of the results to 9.5 mm thick pipe segments X100Q could be realized successful

Thank you for your attention!

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II-VI HIGHYAG

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