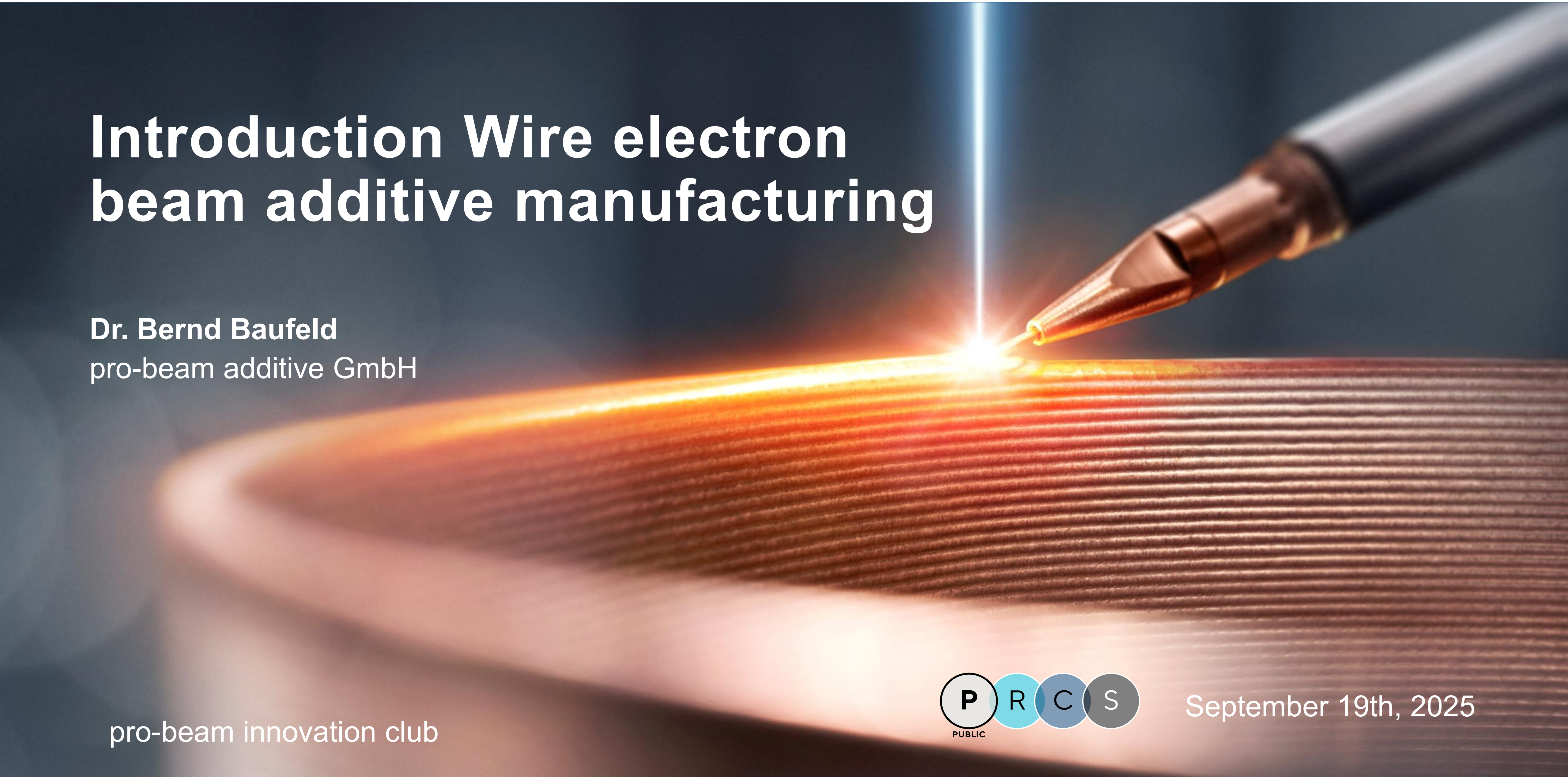

Introduction Wire electron beam additive manufacturing

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P R C S
PUBLIC

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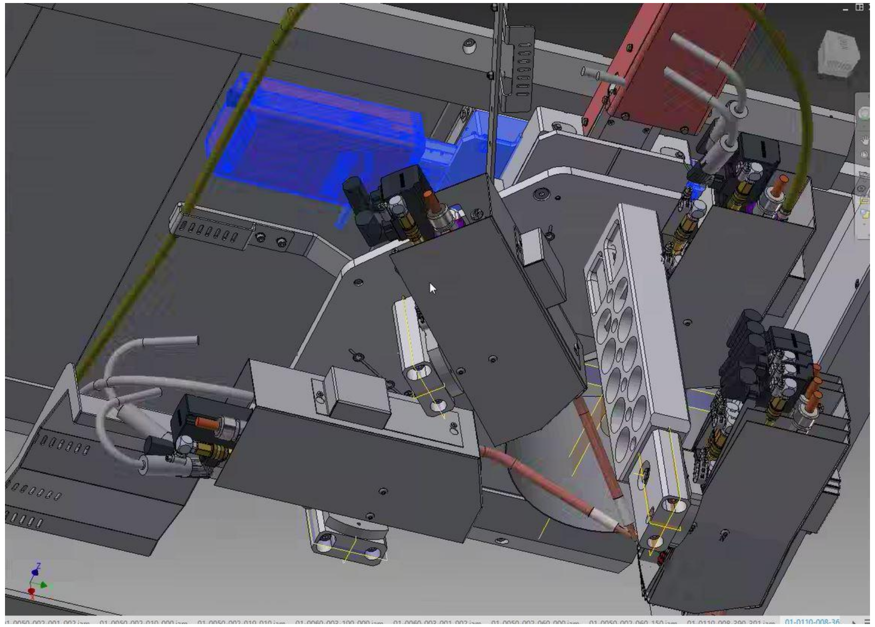
pro-beam innovation club

Wire electron beam additive manufacturing (WEBAM)

What can a wire feeder bring to electron beam welding?

pro beam

- Wire electron beam additive manufacturing
  - Create semifinished products with freedom in geometry, size and material
- Repair
  - Replace lost material
- Compensation for imprecise joint preparations or gaps between components
- Alloying and cladding
  - To improve properties of weld or surface (wear resistance, oxidation resistance, …)



Machines and pro-beam differentiators

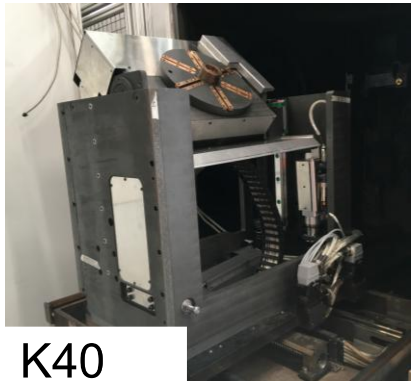
Machines with wire feeder available at pro-beam

pro beam

- 4 machines with wire DED capabilities available
  - PB WEBAM 100: multi-axis machine
  - K40: multi-axis machine
  - K190: tubular machine
  - K6000-1: machine for large and heavy components, internal robot-controlled generator

	PB WEBAM 100	K40	K190	K6000-1
X [mm]	1270 (T)	420 (T)	4900 (T)	11400 (G, WF)
Y [mm]	800 (T) [+ 1100 (G, WF)]	435 (T)	50 (G, WF)	2000 (G, WF)
Z [mm]	1200 (T)	317 (T)	220 (WF)	6000 (G, WF)
Further axes	A (±90), C(∞)	A(+90), C (∞)	A (∞)	A (∞), C (∞)
Beam power [kW]	9	7.5	45	40

WEBAM 100



K40

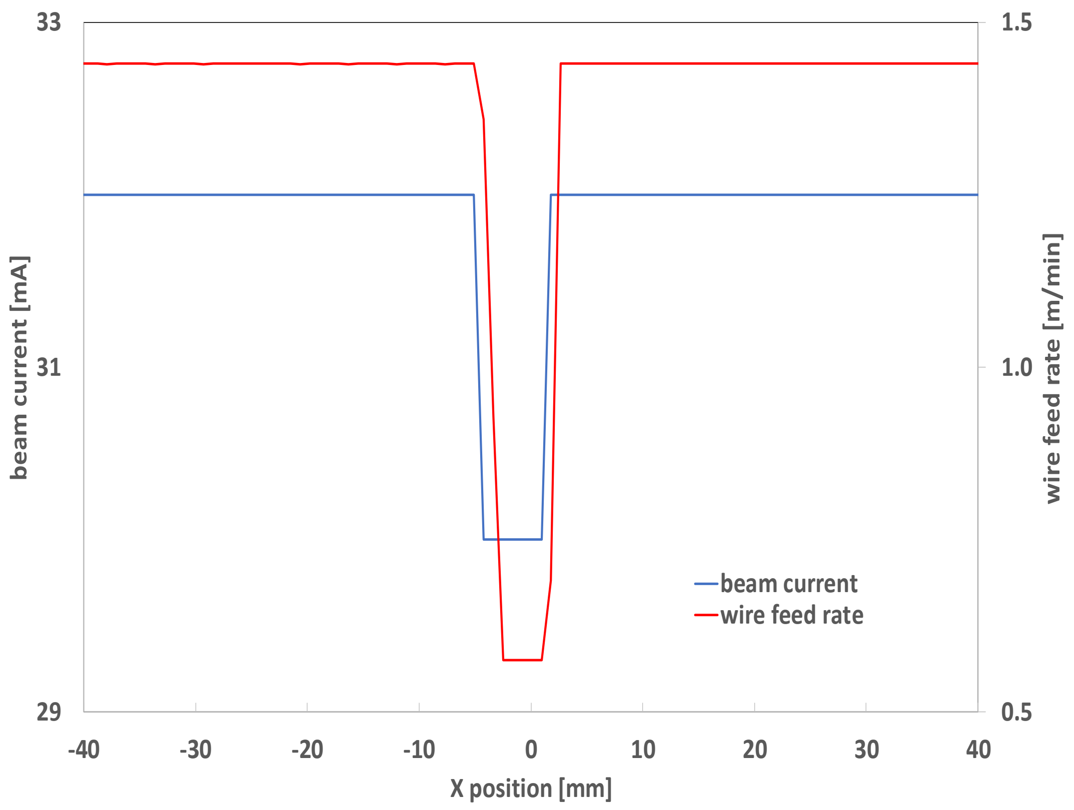
K190

K6000-1

Computerized numerical control

pro beam

- CNC of all relevant mechanical (including wire feed rate) and electron beam parameters
  - G-code
- Manual changes during development phase also possible
- Example: In-process WEBAM data (beam current, wire feed rate, x position)



CAD/CAM, currently via Siemens NX

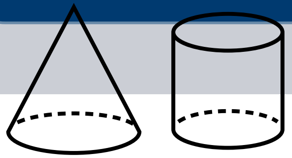
pro beam

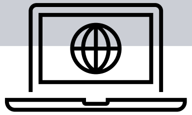
Import CAD data

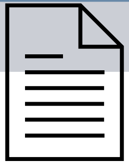
Generate tool path

Machine simulation movement

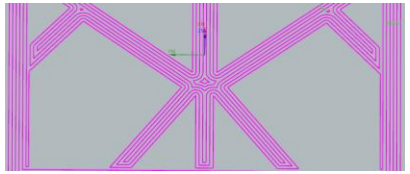
Export validated CNC code

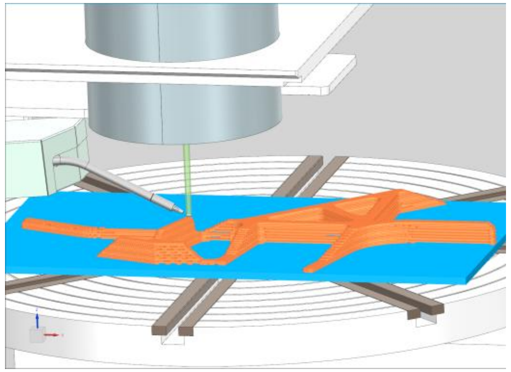






.stp,
.stl, .prt,
.obj, etc.

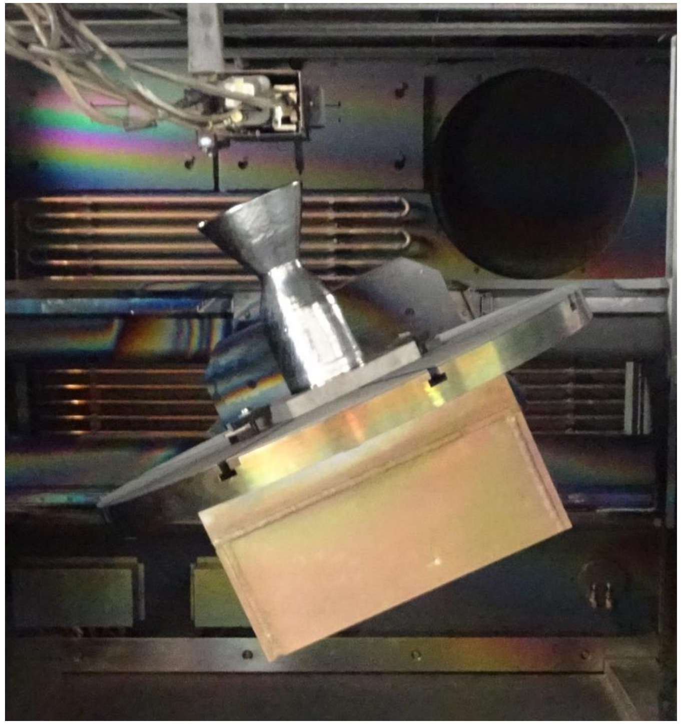


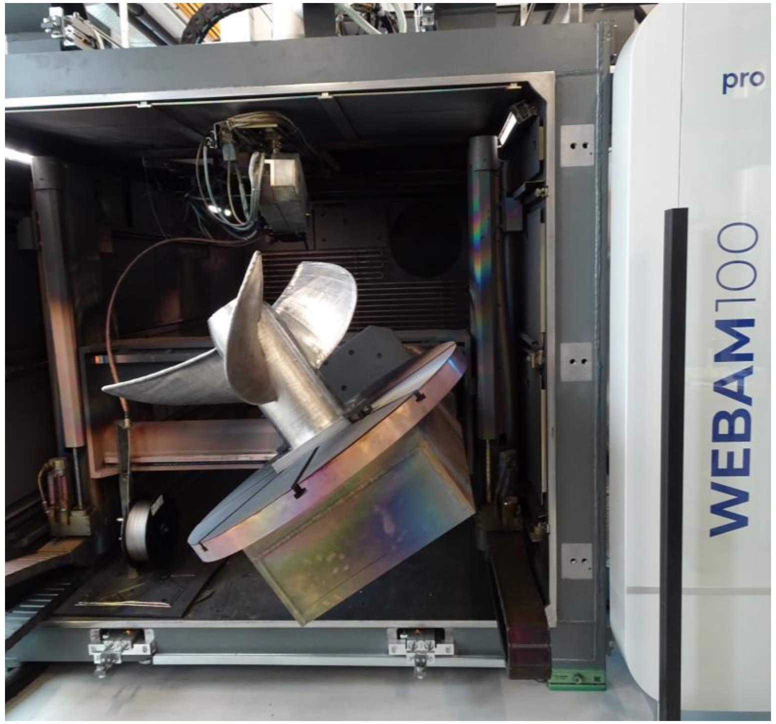


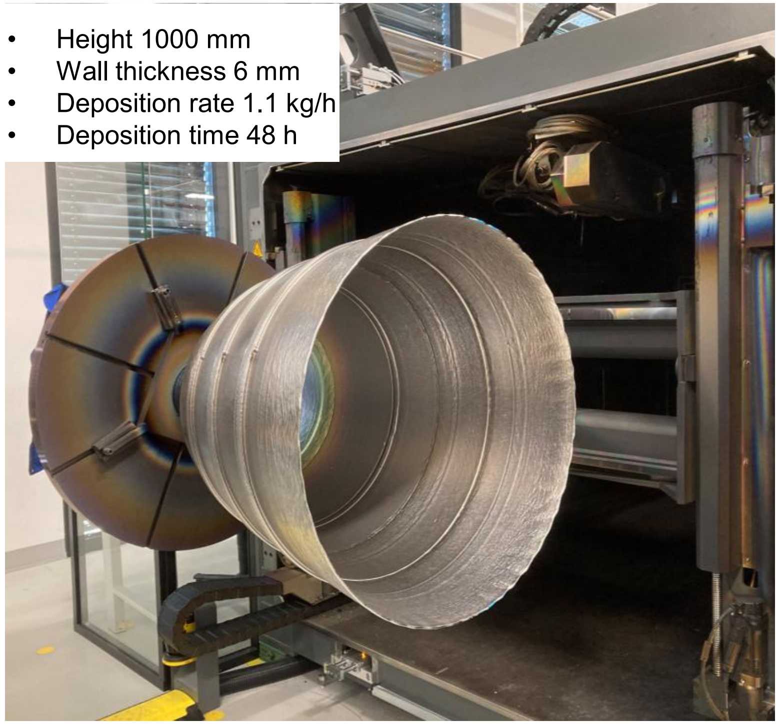
```
;==================================================================
;-- SUBROUTINE: wire Start
;==================================================================
Process_Start:

    G1 G91 Z = -_Lift  Fms 5
    STOPRE

    G0 SQ _SQs)                         ; Beam on

        WF_CTRL("FEED_ON",_Feedrate,1); run WF with "_Feedrate"

    G4 F0.7                             ; time for fill-in

RET
```

Complex titanium components realized by CAD/CAM

pro beam





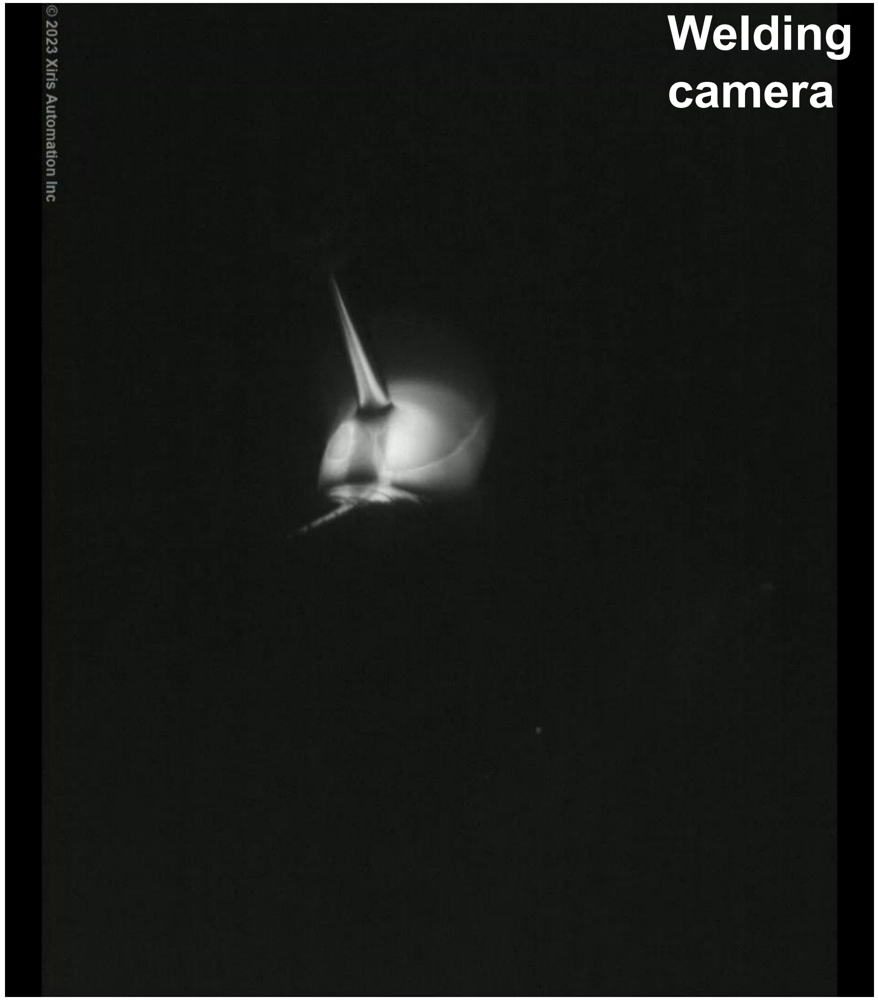


- Height 1000 mm
- Wall thickness 6 mm
- Deposition rate 1.1 kg/h
- Deposition time 48 h

Process-documentation

pro beam

- **Automated data logging** of all important process parameters at 10 Hz (up to 60 different parameters)
  - Beam parameters (current, voltage, oscillation, …)
  - Mechanical parameters (X, Y, Z, rotation angle, …)
  - Feed rate
  - Temperature
  - Wire parameters (wire feed rate, 2n wire feed rate to document slip, …)
  - Vacuum



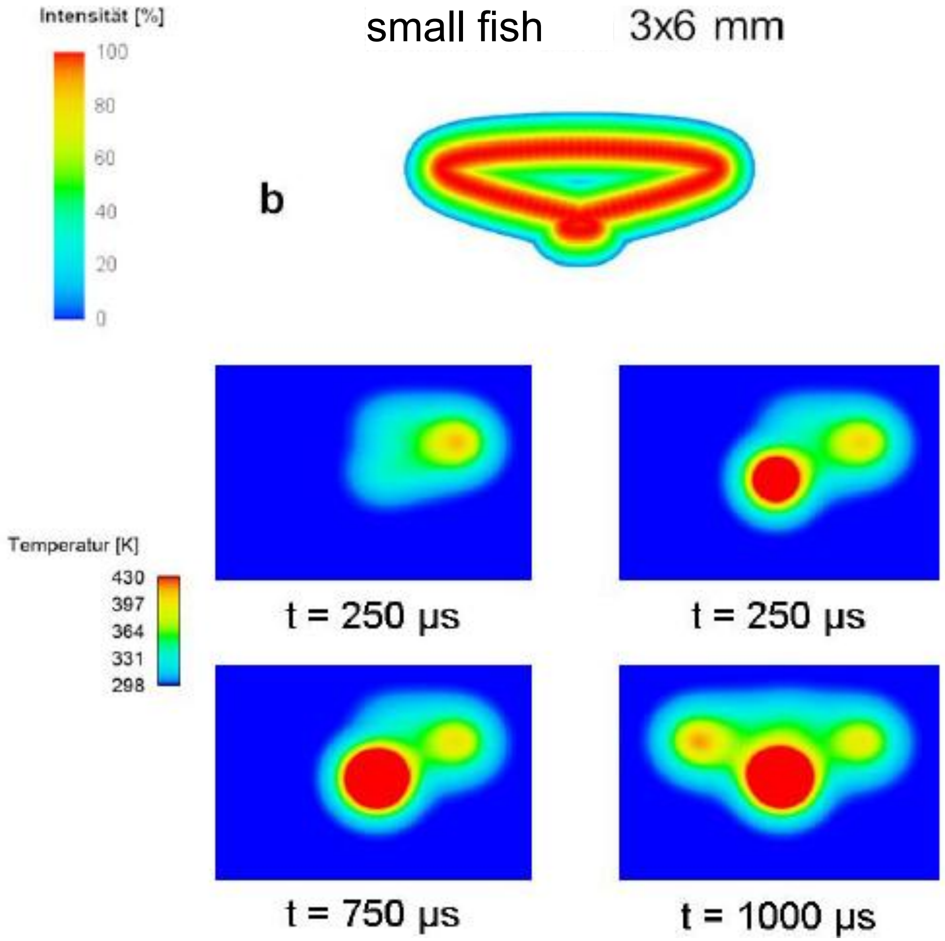
Key process parameters

Similar to most DED technologies:

- Feed rate, wire feed rate, layer height, power (voltage, beam current)

Unique for WEBAM:

- Energy density distribution by beam oscillation
  - Oscillation freely programmable (for example, the wire area can be considered)
  - Size (x, y) and frequency can be programmed
  - Separation in two energy density distributions for wire and melt bead area can be programmed
  - Beam current for these areas can be changed separately over the layers
- Focus position can be controlled



Free control of energy density distribution

Size and shape of oscillation determines wall width

- Depending on oscillation different wall widths possible
- One wire diameter (1.2 mm) can result in single track wall widths between 5 mm and 15 mm

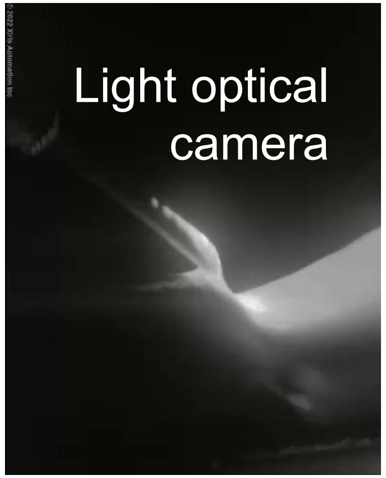
Process documentation

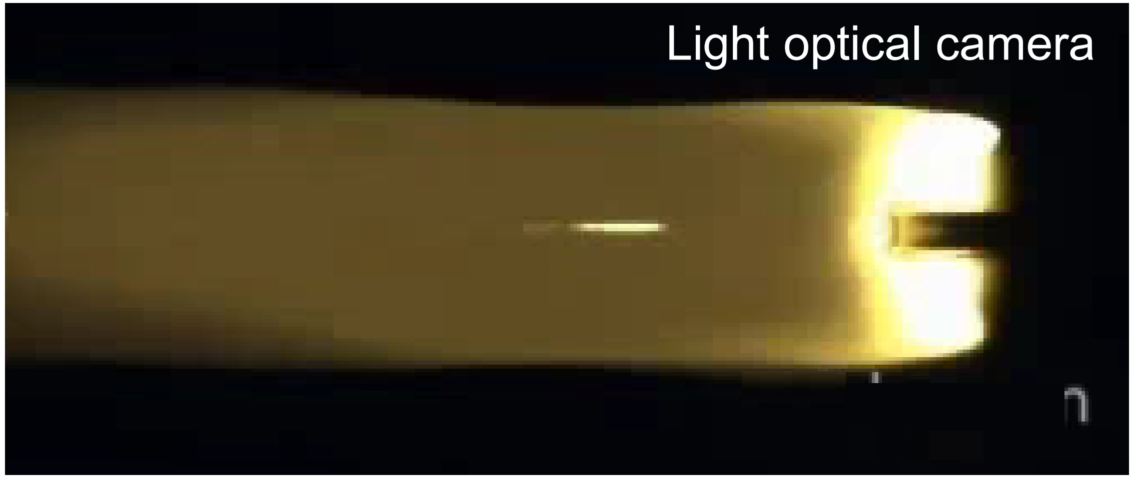
pro beam

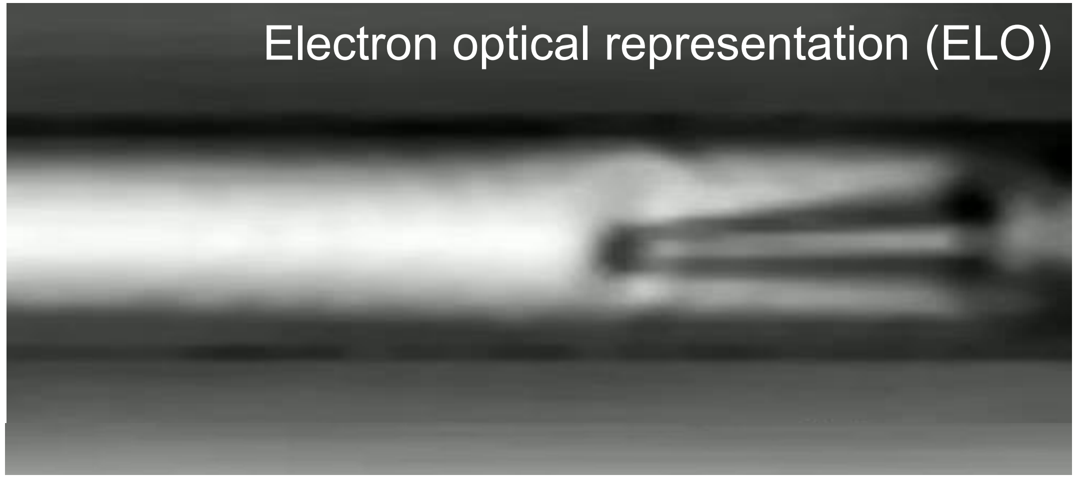
Visual systems

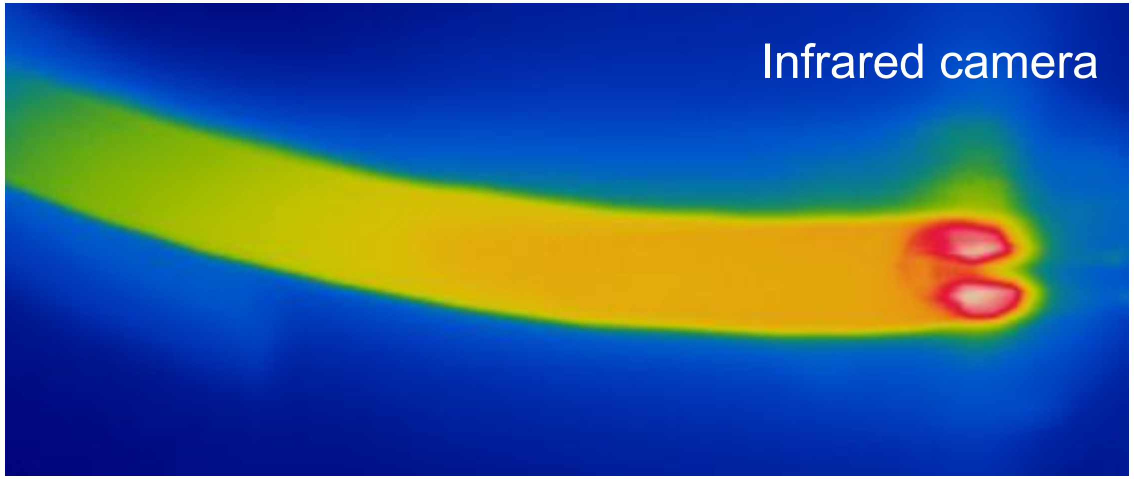
- In-situ process monitoring for parameter development
- Documentation of the melt bead

Thermocouples





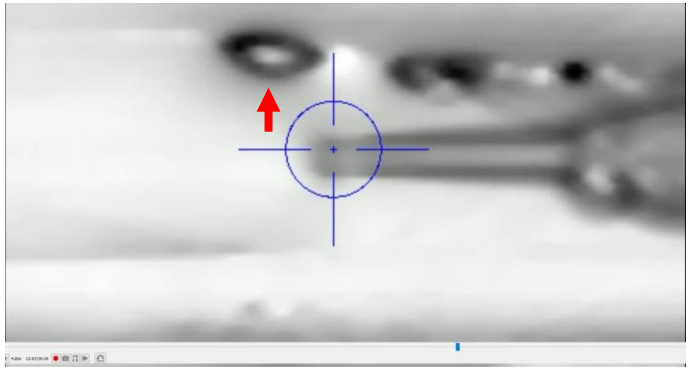




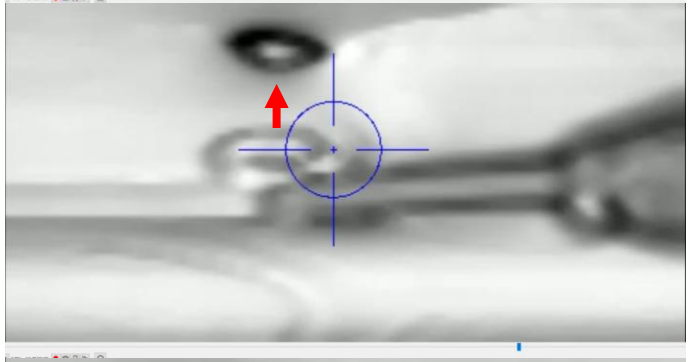
In process ELO defect detection

pro beam

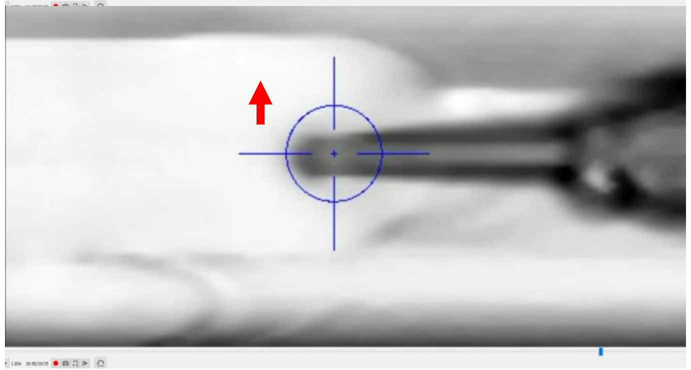
Layer 7, track 3, leading wire 12:56



Layer 8, track 3, trailing wire 14:40



Layer 9, track 3, leading wire 16:56



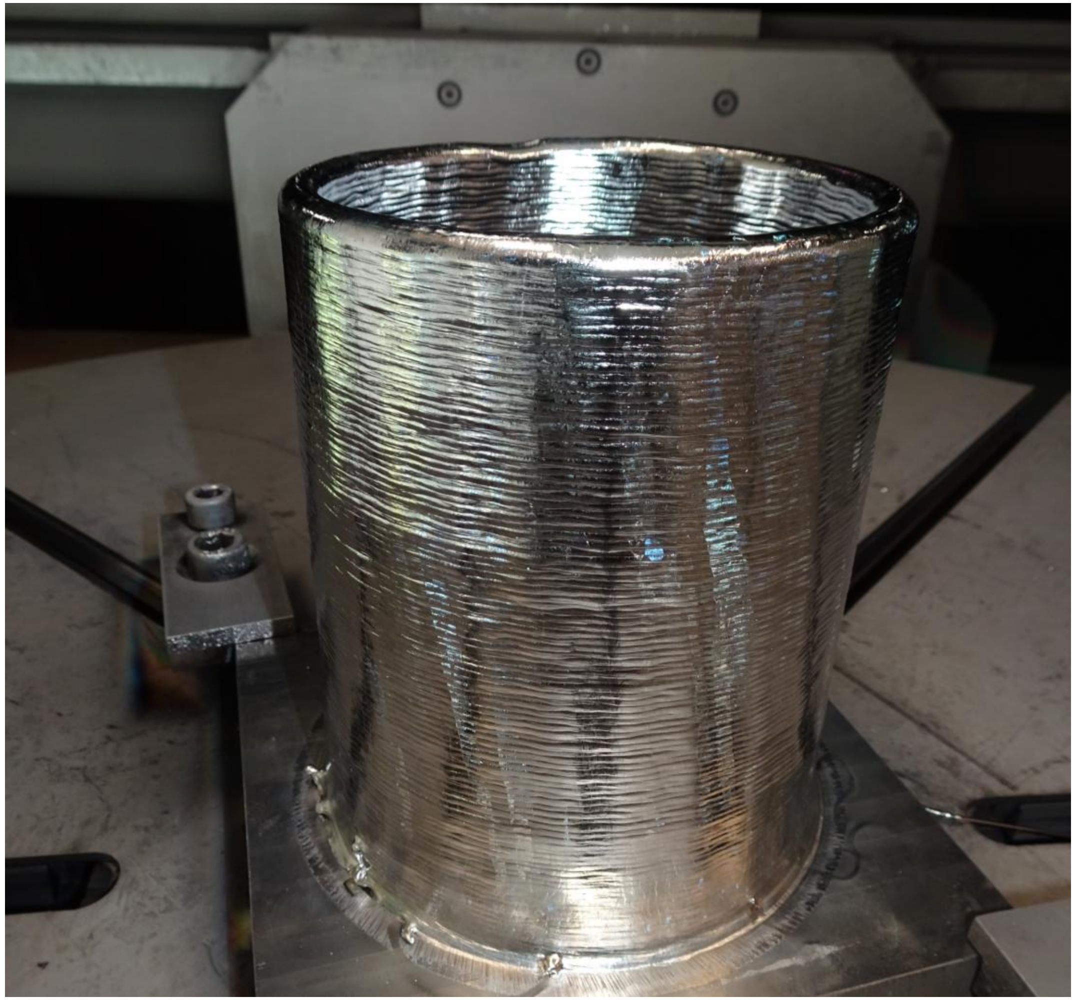
High productivity

pro beam

High deposition rates achieved

- Using 1.6 mm instead of 1.2 mm almost doubles deposition rate
- Continious process (Cylinder)
- Deposition rates lower for structural components

Material	Deposition rate [kg/h] max	Volume deposition rate max [cm^3/h]
Copper	13.0	1448
Inconel 718	11.9	
Ti64	6.4	

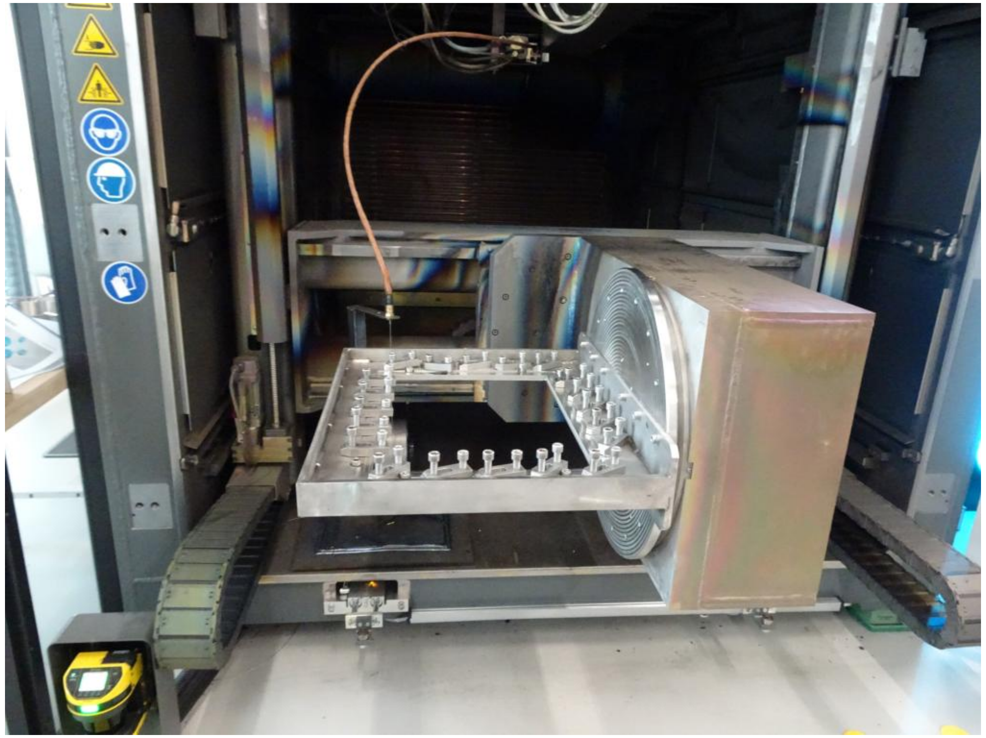


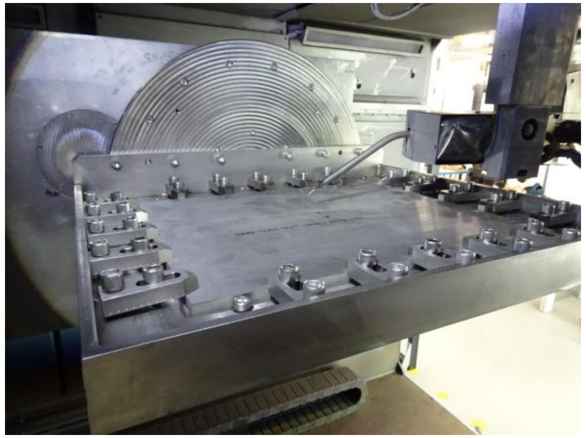
Flip frame to reduce thermal distortion

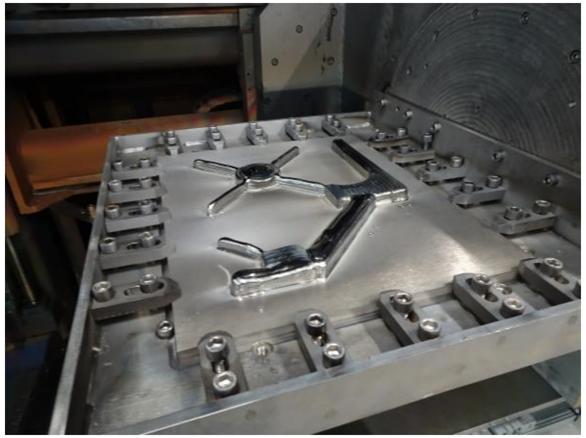
Flip frame

pro beam

- Flip frame to reduce thermal distortion
- Flip at high vacuum within 1 min
- 500 mm x 400 mm x 10 mm
- (RIB5 slightly too long, but new frame possible)

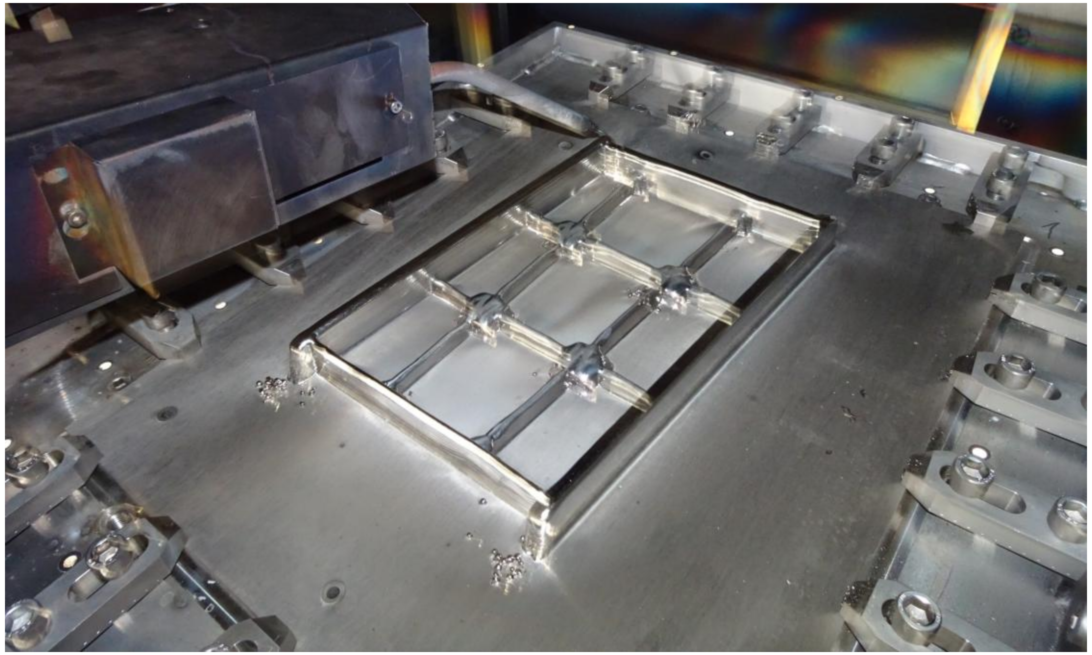


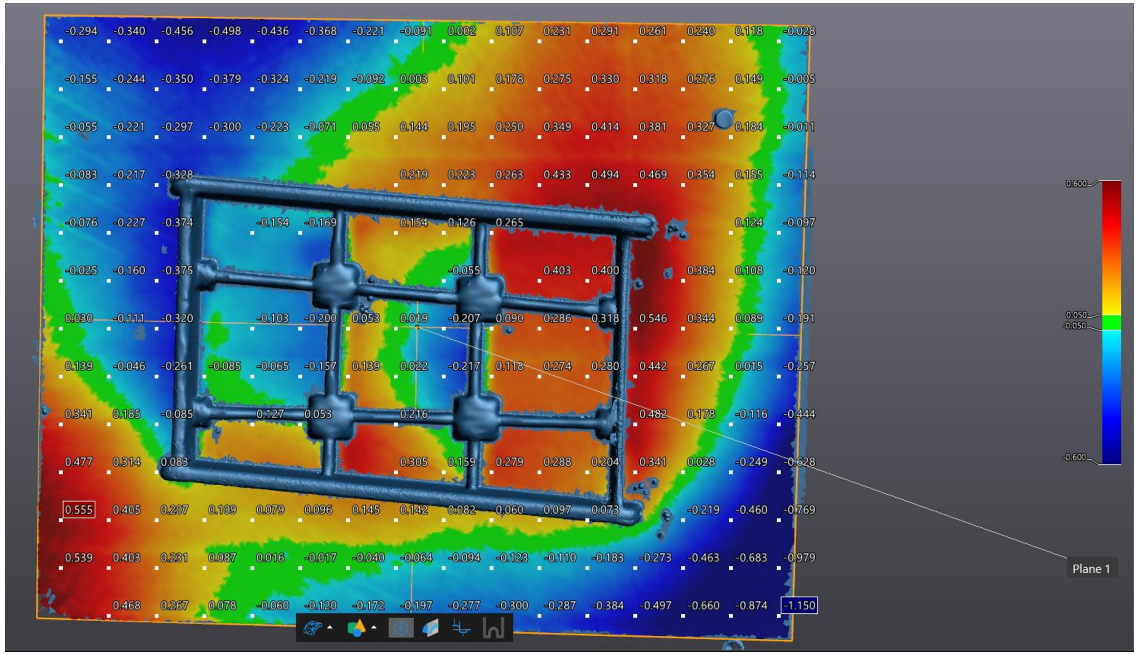


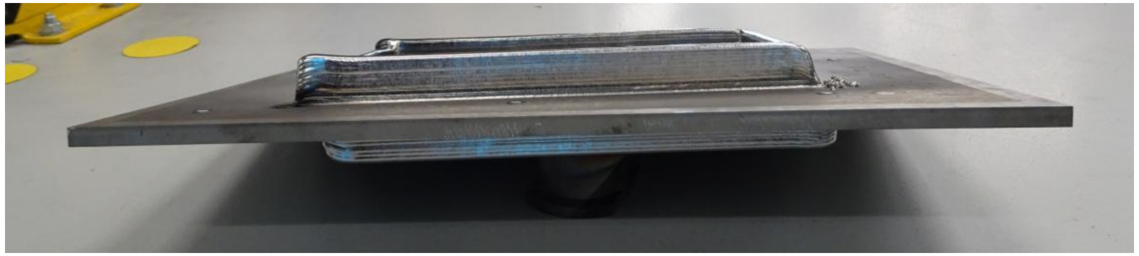


Example for result with flip frame

pro beam







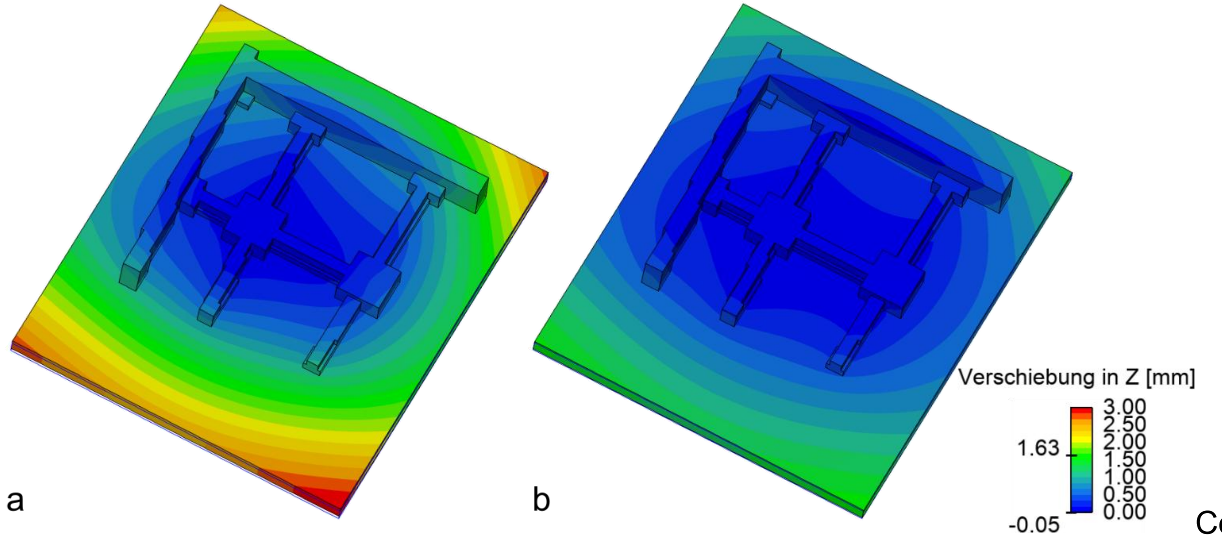
- Build time 5:22 h, 8 min each layer
- 21 layers each side, flip after each layer
- Maximum z thermal deformation <1 mm

Minimizing thermal deformation by thermal management

Minimizing thermal deformation by thermal management

pro beam

- Working at high vacuum, the electron beam can be used for
  - Pre-heating, in-process-heating, post-process-heating
  - Can be used for in-chamber stress relief at high vacuum (under constraint)
- Insulating or improved thermal contact of the base also affects the thermal deformation



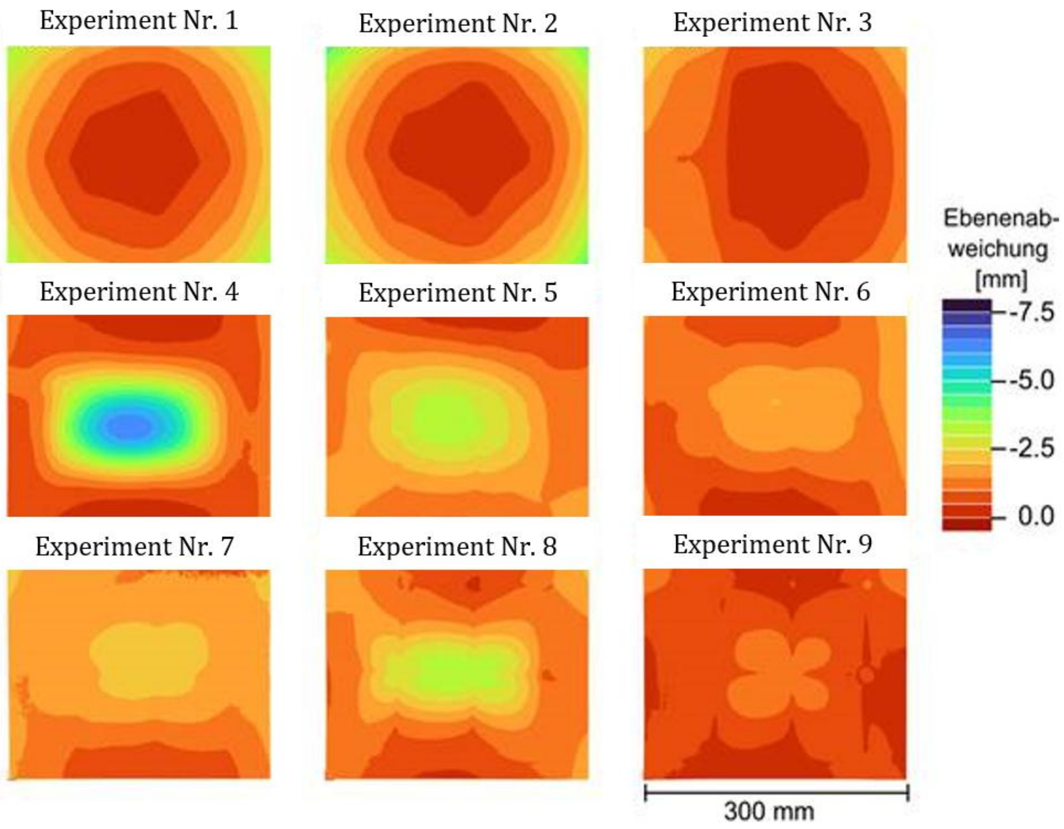
Courtesy NMF

Simulation of z thermal deformation without (a) and with (b) thermal management

Minimizing thermal deformation by thermal management

pro beam

- Single sided WEBAM
- 300 mm x 250 mm x 10 mm (5 mm)
- Different thermal management gives different thermal deformation
- Less than 2 mm deformation for a 5 mm plate



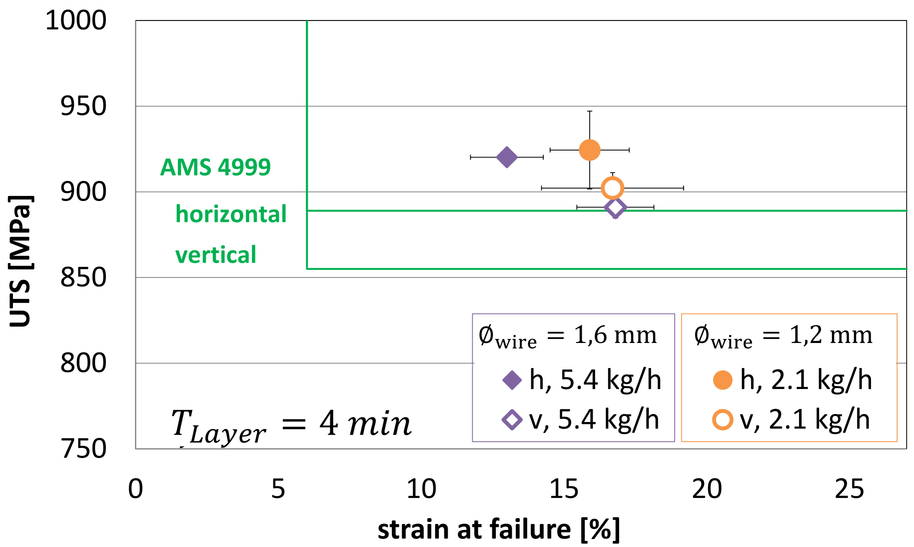
Back side of plate by laser scanning (z displacement)

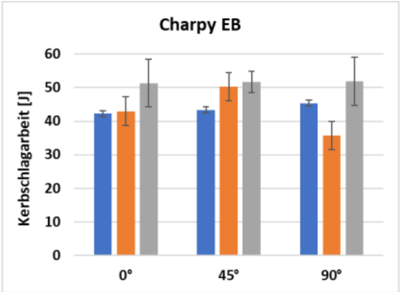
Material properties and microstructure

Material properties Ti6Al4V

pro beam

- Material properties depend strongly on process parameters, but parameters available to suffice requirements of AMS4999
- Example: waiting time T_{layer} = 4 min (not heat treated)
    - UTS and elongation within AMS4999
    - Chemical composition within AMS4999
- No surface contamination and oxygen rich layer (α-casing) due to manufacturing at high vacuum

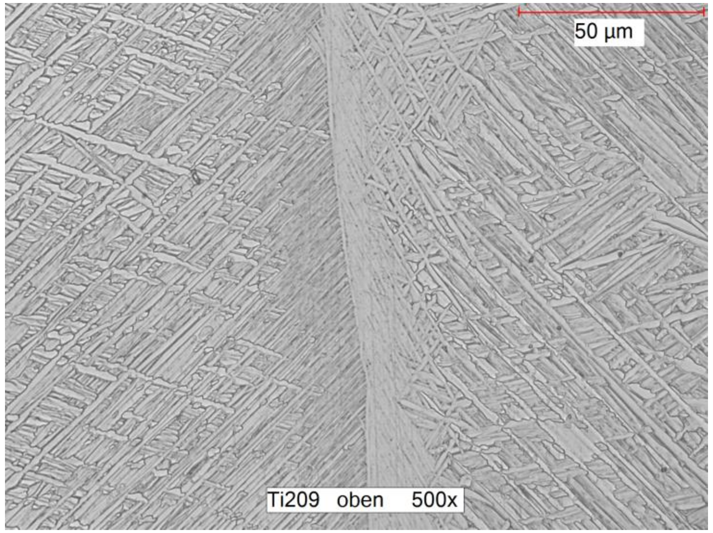


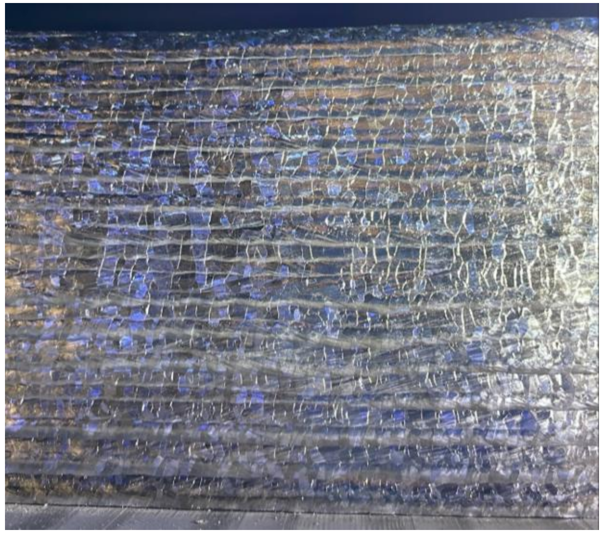


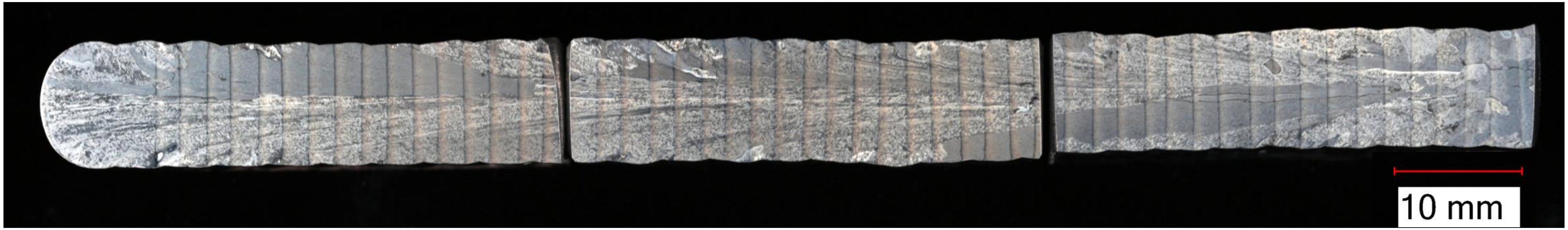
	Al [%]	V [%]	O [%]	Hardness
T Layer = 4 min	5.69	4.3	0.15	HV10 322 ± 6
AIMS03-29-001	5.50-6.75	3.50-4.50	0.20 max	

Microstructure Ti6Al4V

- Microstructure depends strongly on process parameters
- Example: waiting time T_{layer} = 4 min (not heat treated)

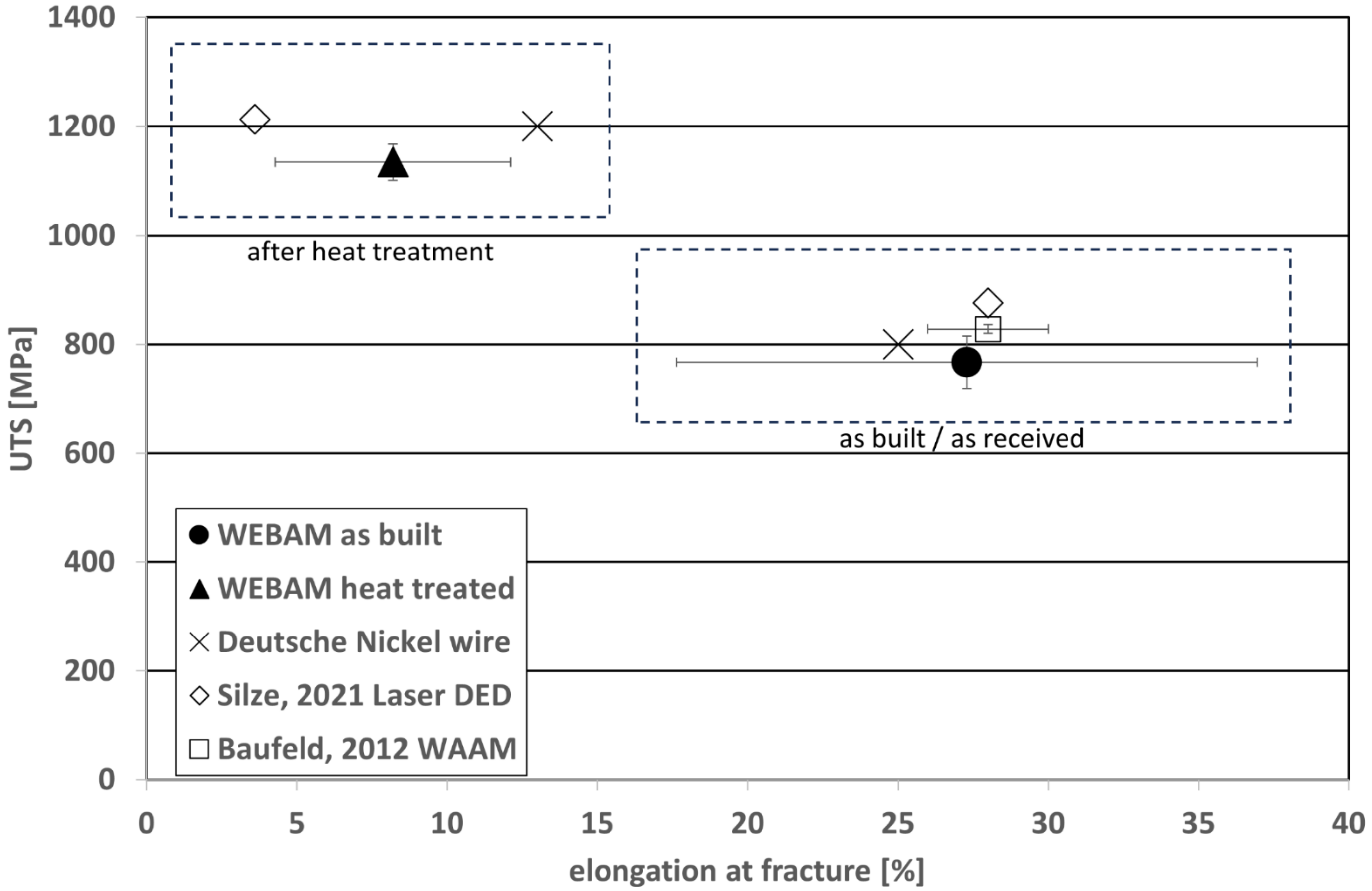






Mechanical properties of IN718 deposited at 11.9 kg/h

- Properties comparable to literature values
- Heat treatment increases strength and decreases elongation at fractur



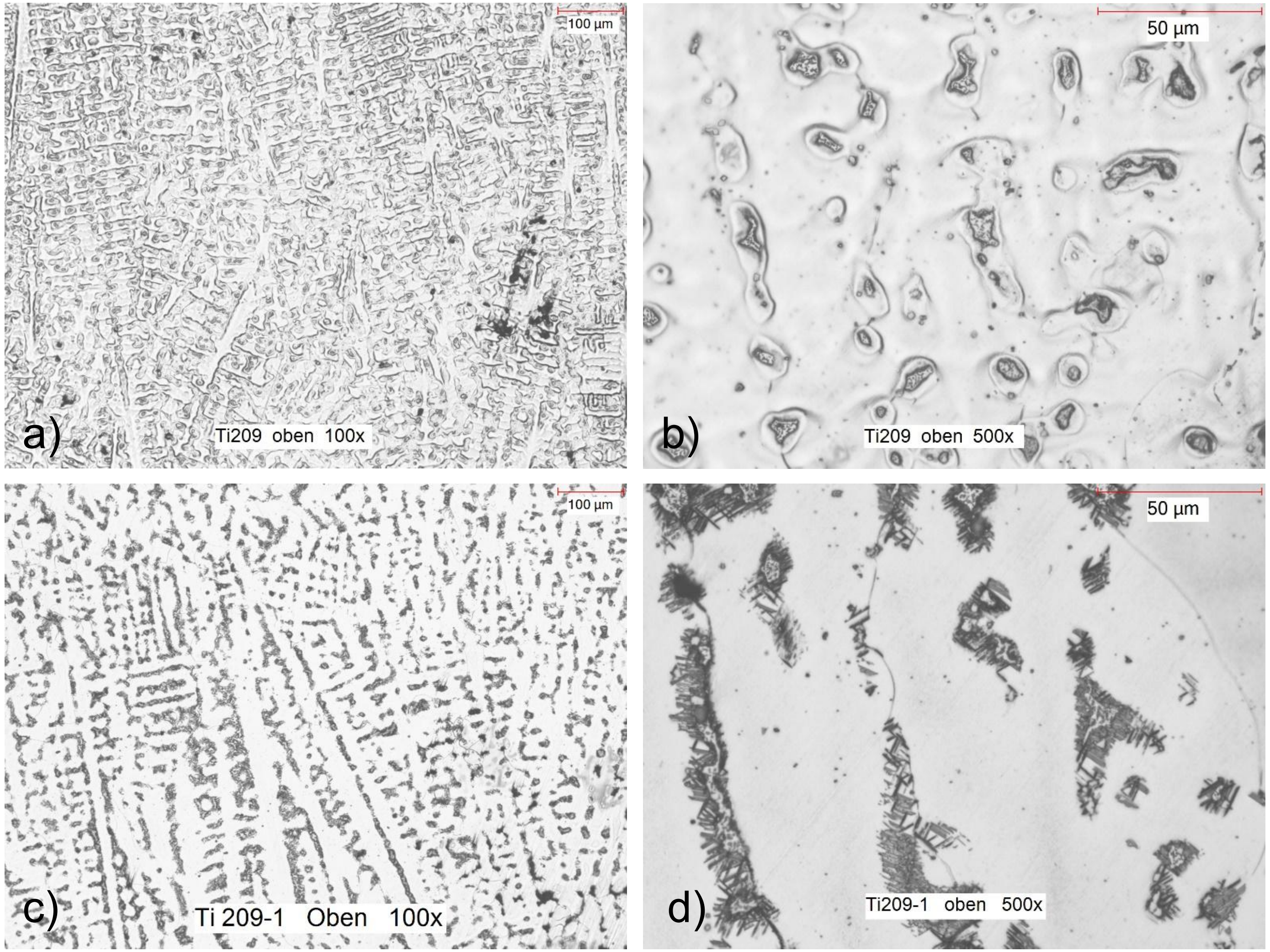
Mikrostruktur IN718

pro beam

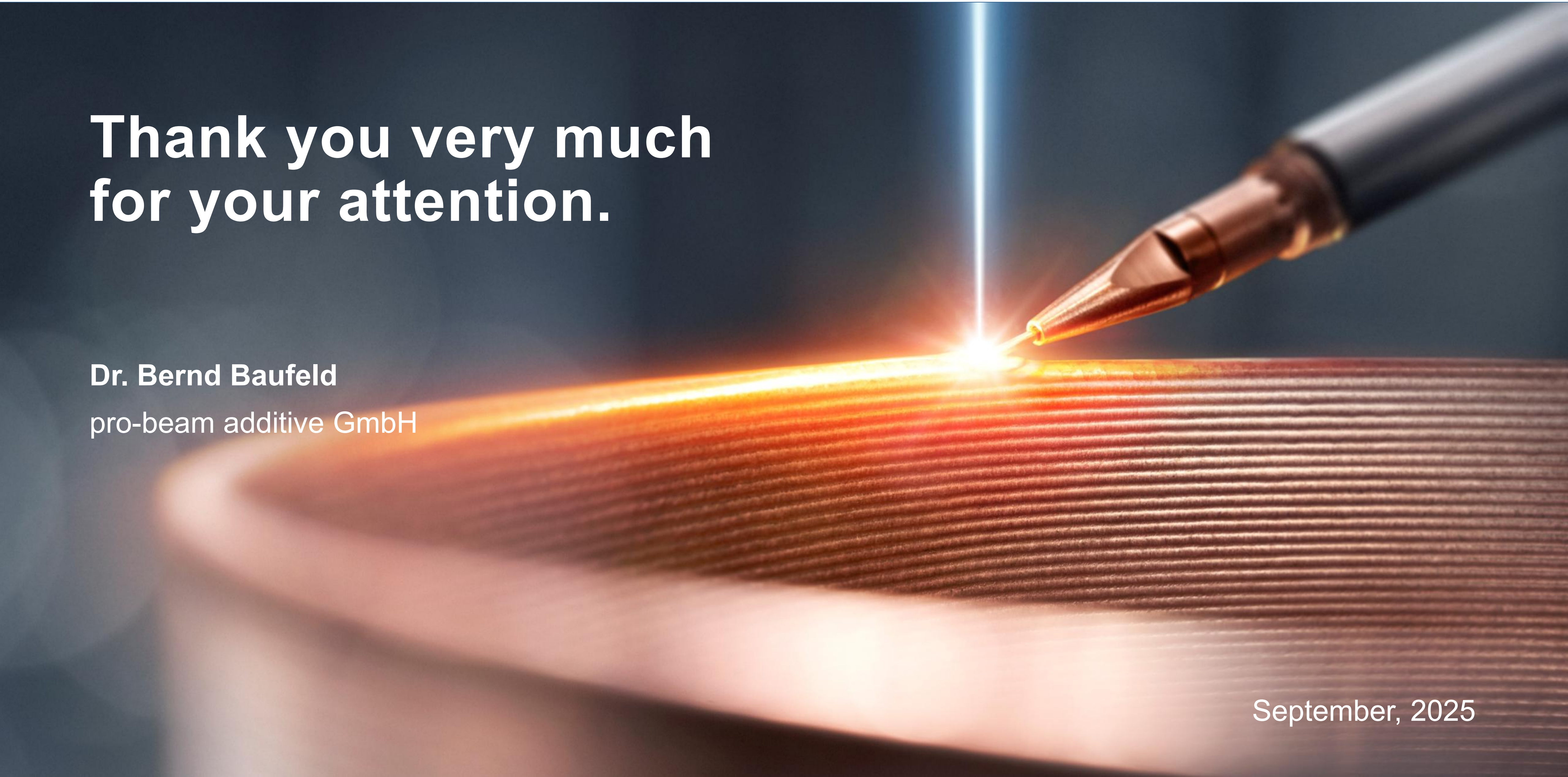
- Microstructure near the top of the cylinder in the as-built (a, b) and the heat treated state (c, d) at low (a, c) and high magnification (b, d)

b)

c)



pro beam



Thank you very much for your attention.

Dr. Bernd Baufeld

pro-beam additive GmbH

September, 2025