TUBAF
Die Ressourcenuniversität.
Seit 1765.

SEAMAC
STRENGTHENING THE EXCELLENCE OF ADDITIVE MANUFACTURING CAPABILITIES

INTRODUCTION TO PEP

SEAMAC International Summer School 2024

SEAMAC International Summer School 2024, Freiberg, Germany

Technische Universität Bergakademie Freiberg (Germany)

AM PROCESS CHAIN

design & CAD/CAM → **material conditioning** → **AM-Process** → **geometry finish** → **surface finish**

design & CAD/CAM
- TopOpt (including surface!)
- Multi-material design
- Hybrid-CAM AM/cutting

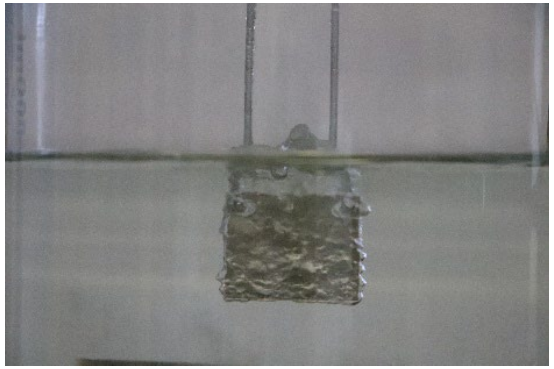
material conditioning
- Powder-conditioning
- classating
- Binder development

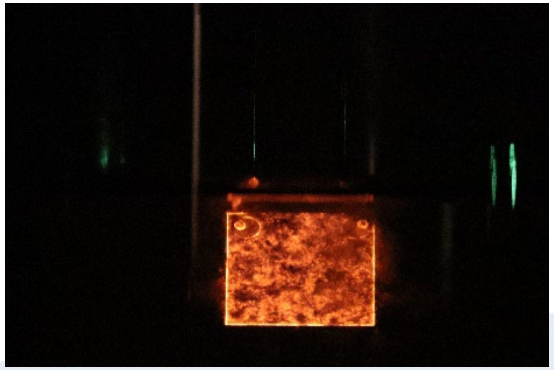
AM-Process
- Multi-Material (wire / powder)
- Graded materials
- Building on top of existing parts
- >5-axis systems

geometry finish
- Hybrid AM/cutting

surface finish
- Plasma-electrolytic Polishing
- Increase fatigue strength
- Selective coating

PeP PROCESS

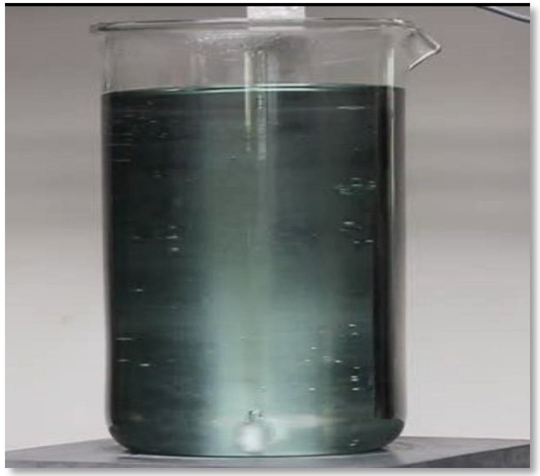




PLASMA-ELECTROLYTIC POLISHING

- Deburring, smoothing, shining of metallic parts
- Complex geometries polishable
- Reduction of roughness -> increase of fatigue strength

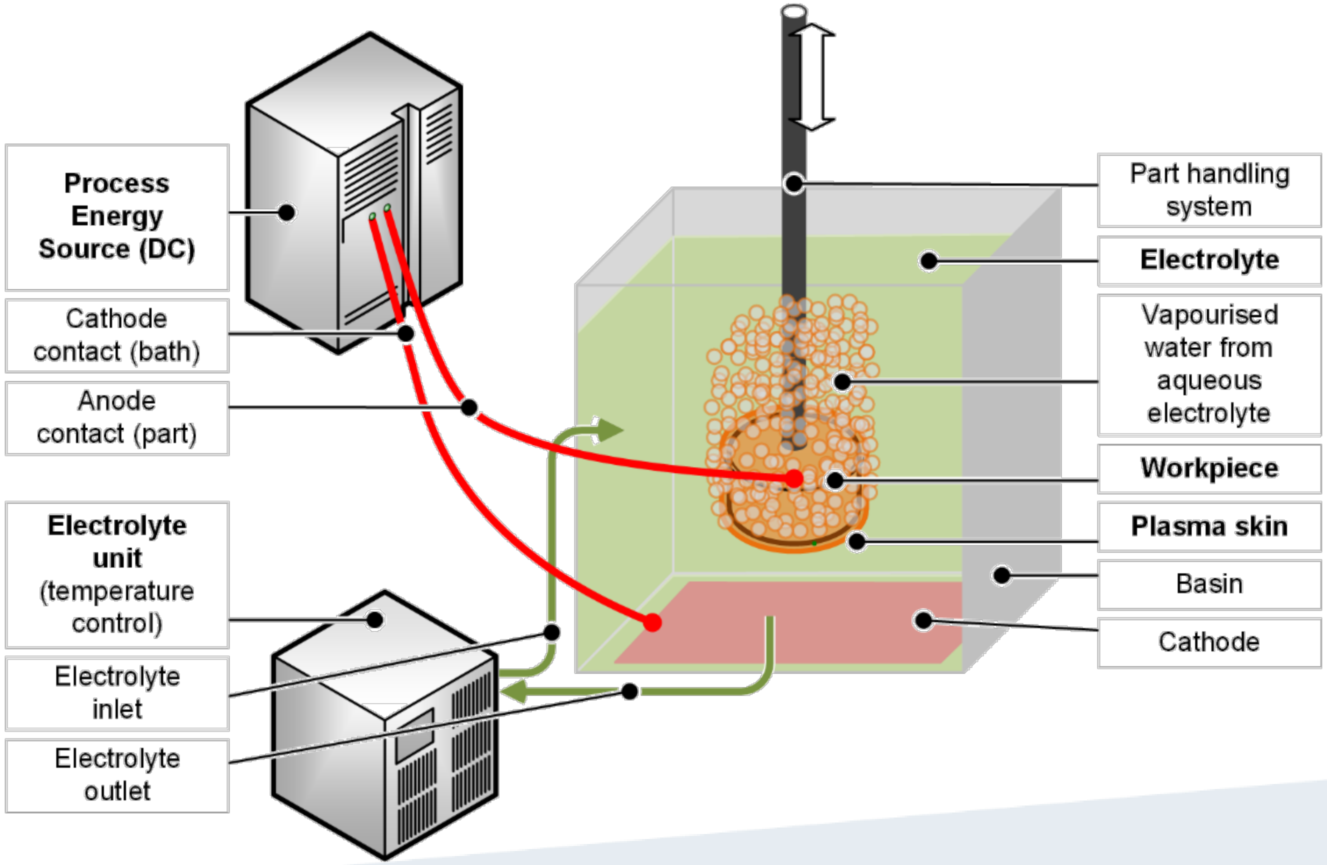
➲ Development of electrolyte/alloy combinations
➲ Development of machinery (part size/selectivity/internal machining)
➲ Definition of surface requirements



PeP of brass (© BTE)

PeP von Titanium dental parts, steel grid, weld lines

PeP SETUP



Process Energy Source (DC)
Cathode contact (bath)
Anode contact (part)
Electrolyte unit (temperature control)
Electrolyte inlet
Electrolyte outlet
Part handling system
Electrolyte
Vapourised water from aqueous electrolyte
Workpiece
Plasma skin
Basin
Cathode

PeP PROCESS PRINCIPLE

Anodic material removal and anodic Plasma at high voltages:
combination of current-induced chemical and physical removal.

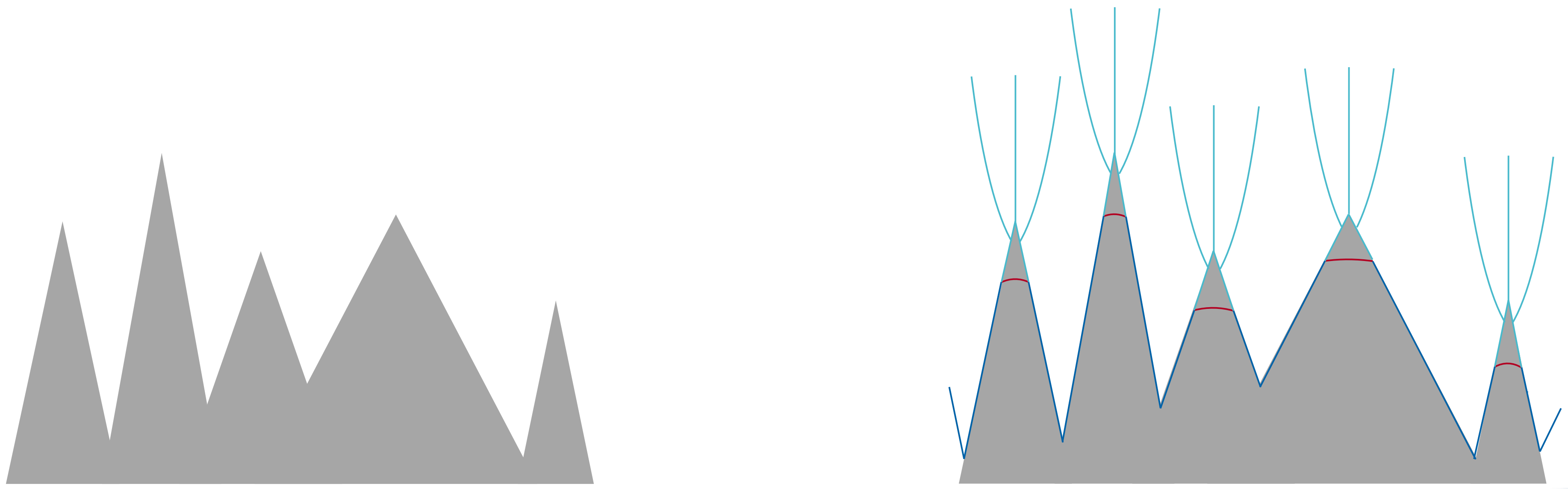
- Electrolytic cell
- Part is immersed in electrolyte, contacted as anode
- Low concentrated aqueous electrolyte, material specific, $4 \leq \sigma \leq 30$ S/m
- DC voltages of $180V \leq u_{PeP} \leq 400V$ lead to formation of plasma skin around the part
- Electrochemical and plasma reactions take place
- Plasma zone in connection with electrochemical processes leads to exceptional surface quality


Untreated part (Ti)

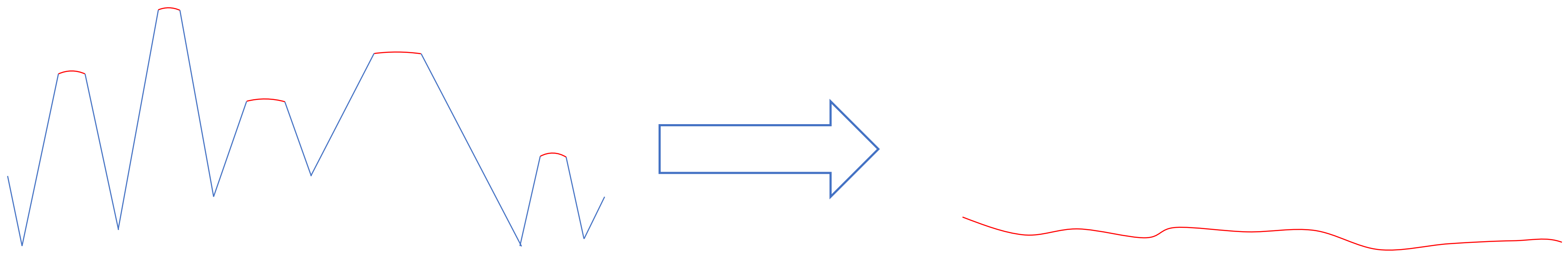

Part during PeP


Polished part

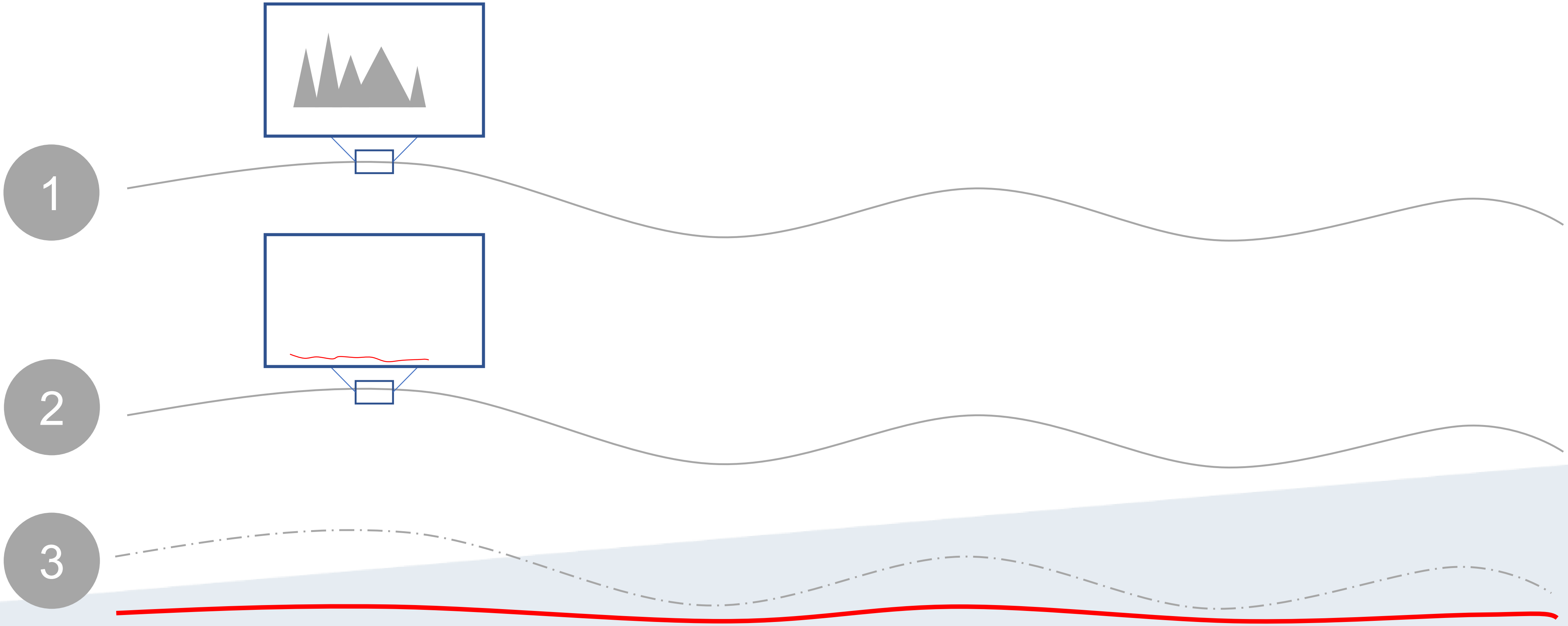
SURFACE MACHINING PROGRESSION IN PeP



SURFACE MACHINING PROGRESSION IN PeP



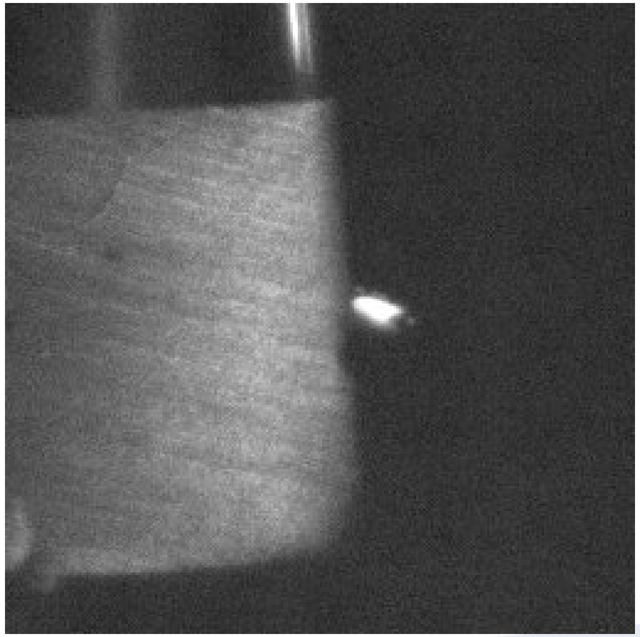
SURFACE MACHINING PROGRESSION IN PeP



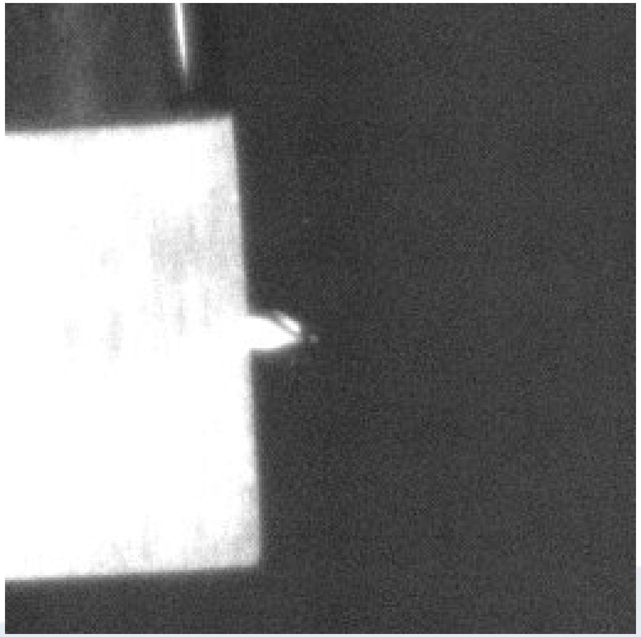
Investigation of plasma-electrolytic polishing (PeP) process initiation

SAMPLE 2 / PROCESS START

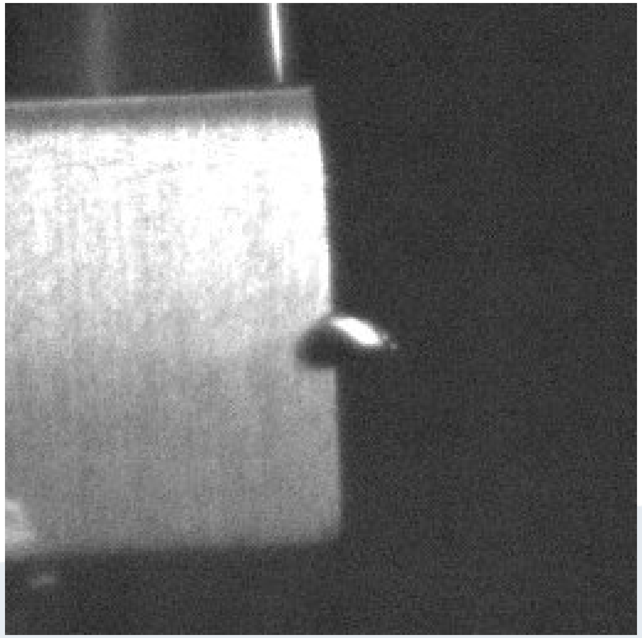
0,0 ms ≤ t ≤ 8,33 ms



316 V



340 V

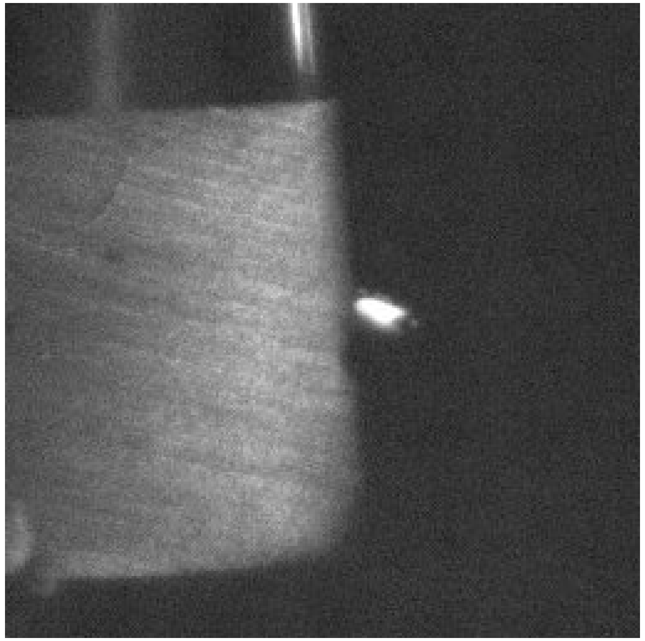


360 V

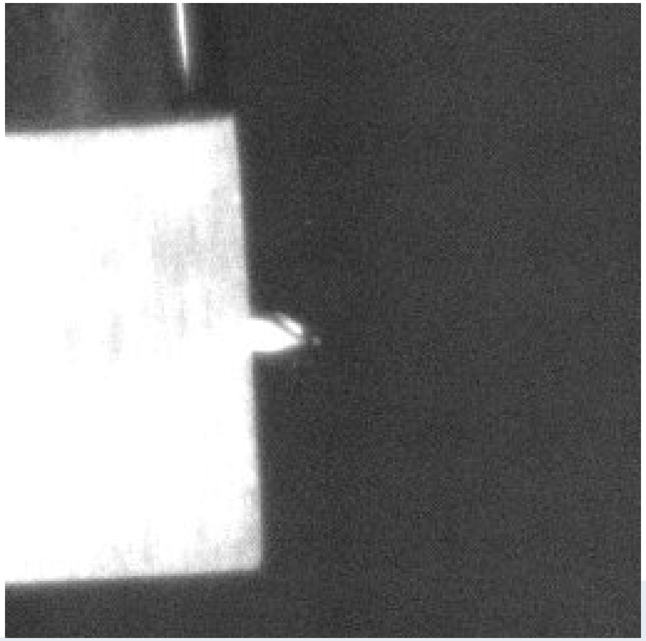
Investigation of plasma-electrolytic polishing (PeP) process initiation

SAMPLE 2 / PROCESS START

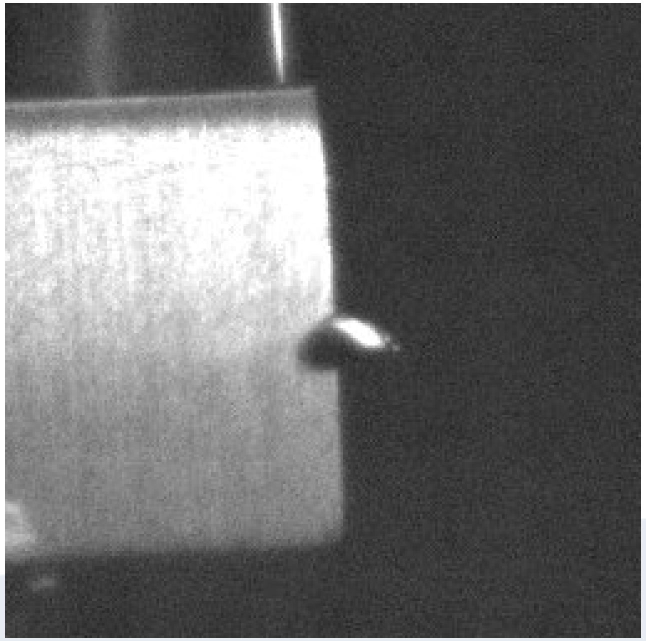
→ t = 0 ms



316 V



340 V

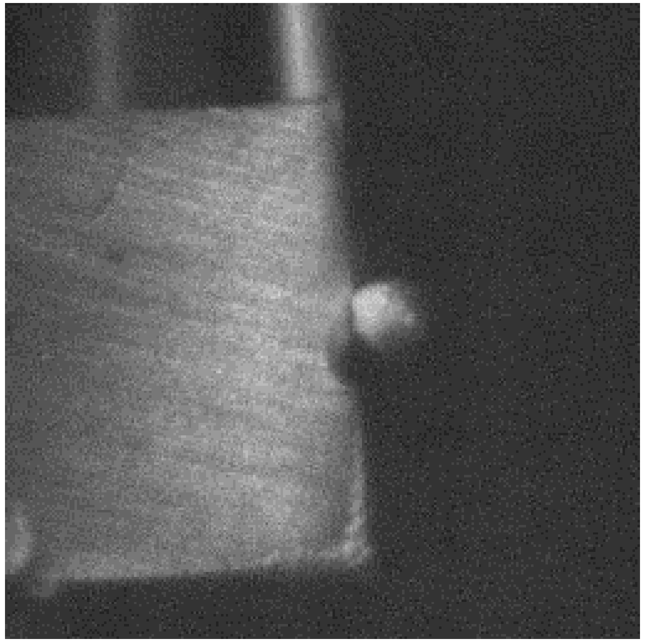


360 V

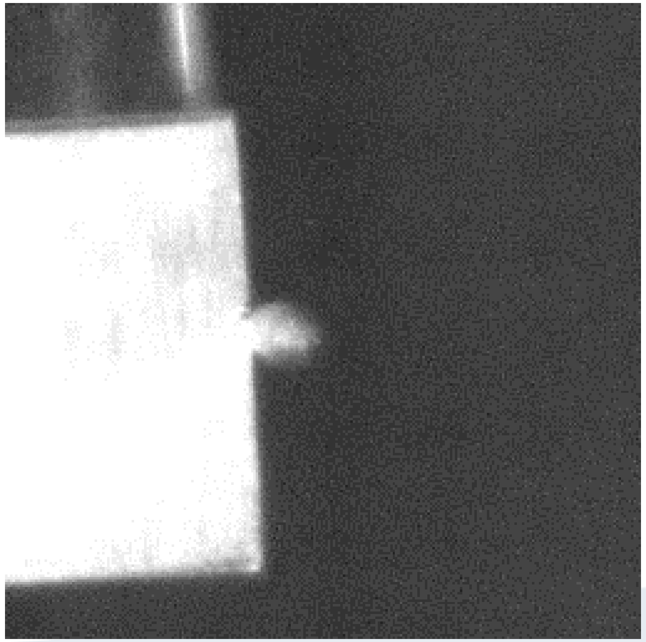
Investigation of plasma-electrolytic polishing (PeP) process initiation

SAMPLE 2 / PROCESS START

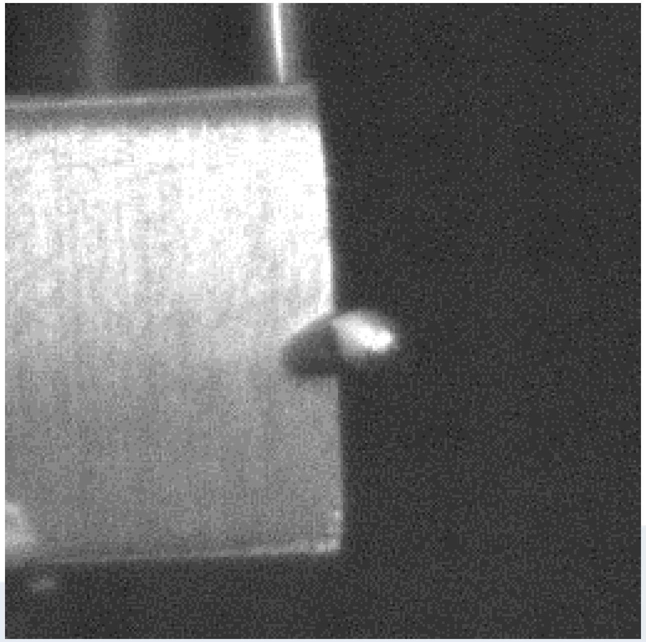
→ t = 0,33 ms



316 V



340 V

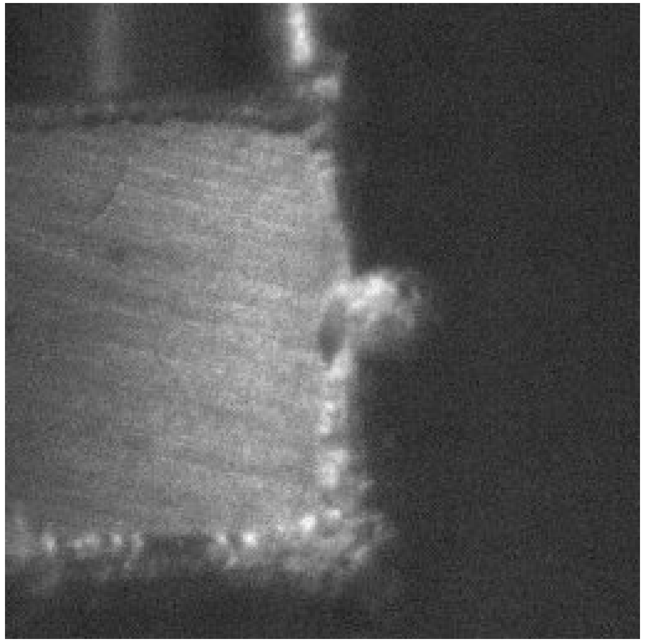


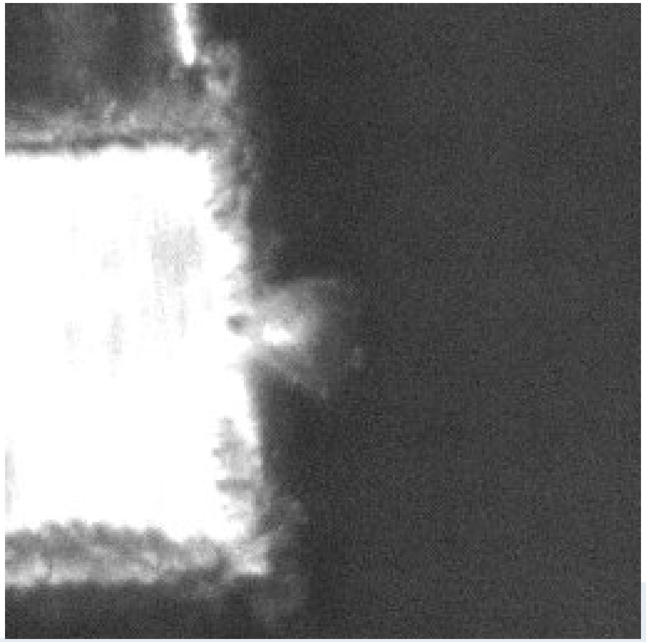
360 V

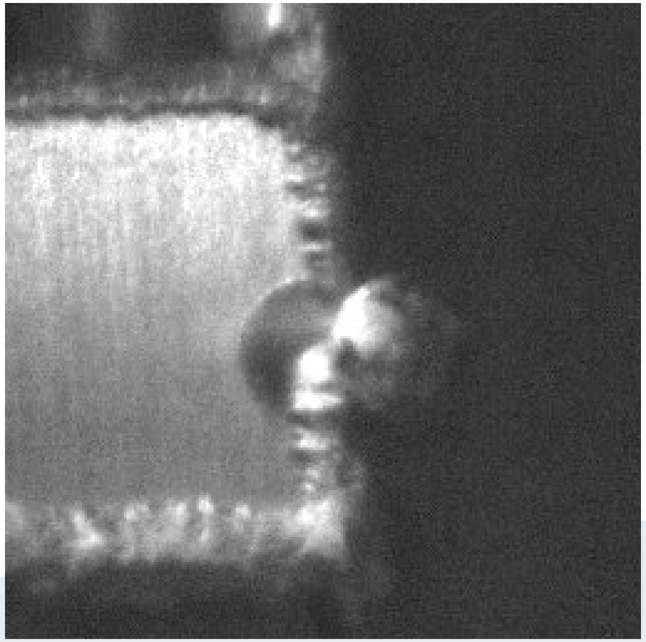
Investigation of plasma-electrolytic polishing (PeP) process initiation

SAMPLE 2 / PROCESS START

→ t = 1,0 ms


316 V

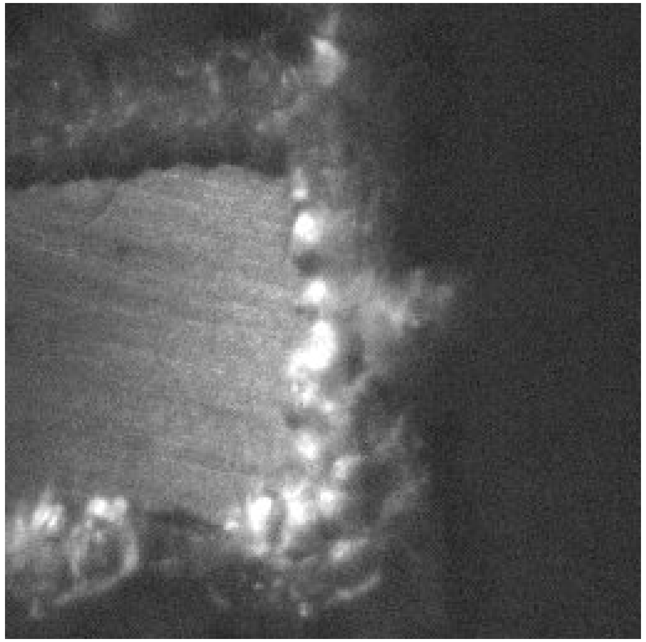

340 V


360 V

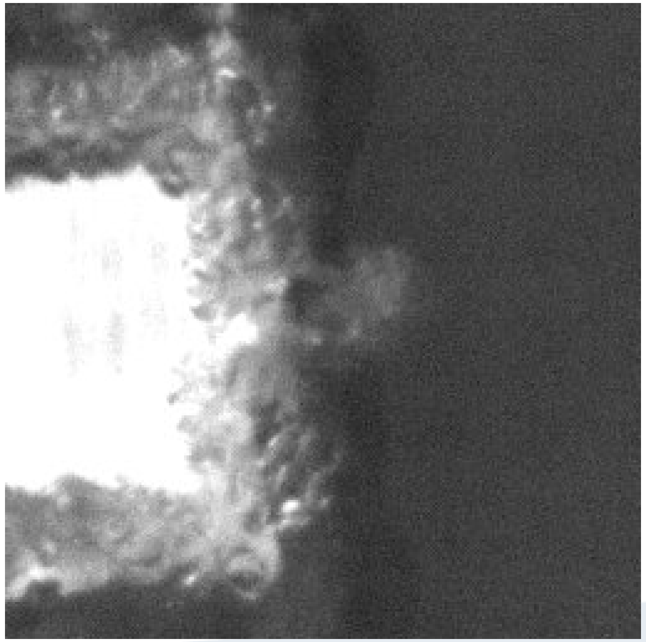
Investigation of plasma-electrolytic polishing (PeP) process initiation

SAMPLE 2 / PROCESS START

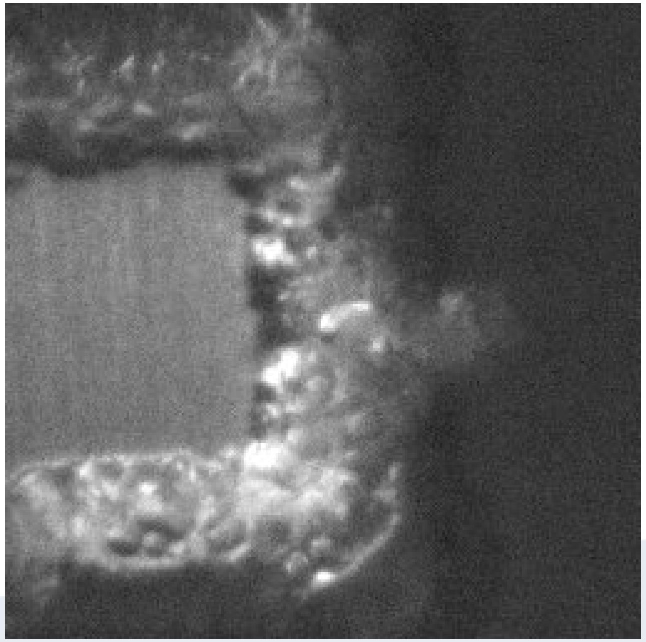
→ t = 2,0 ms



316 V



340 V

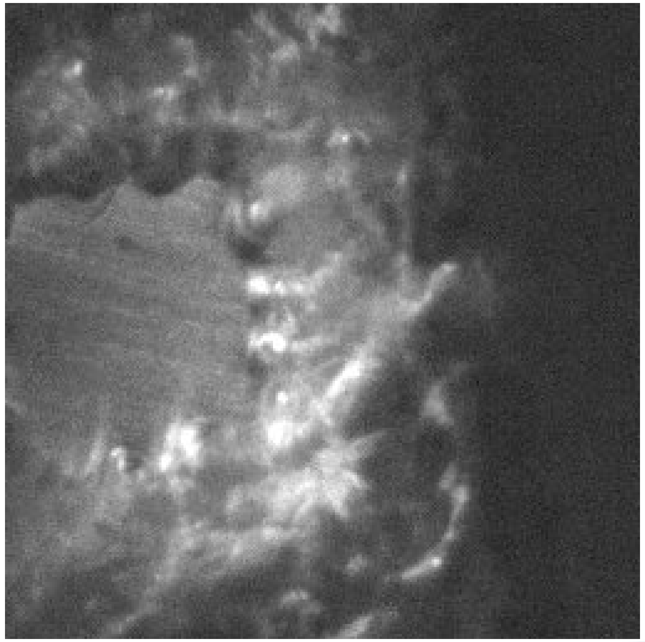


360 V

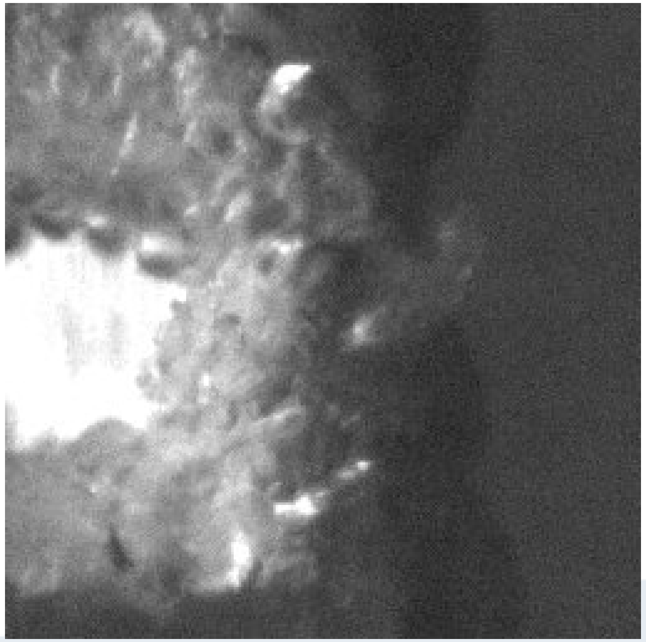
Investigation of plasma-electrolytic polishing (PeP) process initiation

SAMPLE 2 / PROCESS START

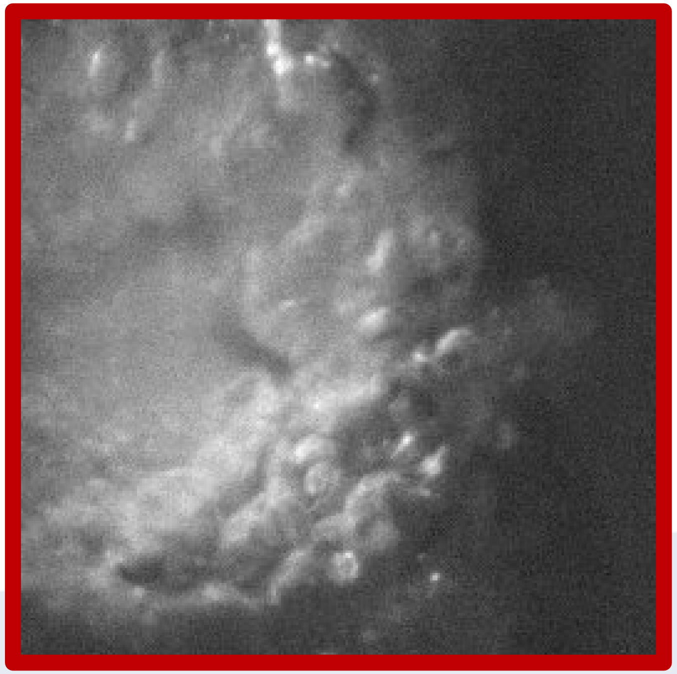
→ t = 3,17 ms



316 V



340 V

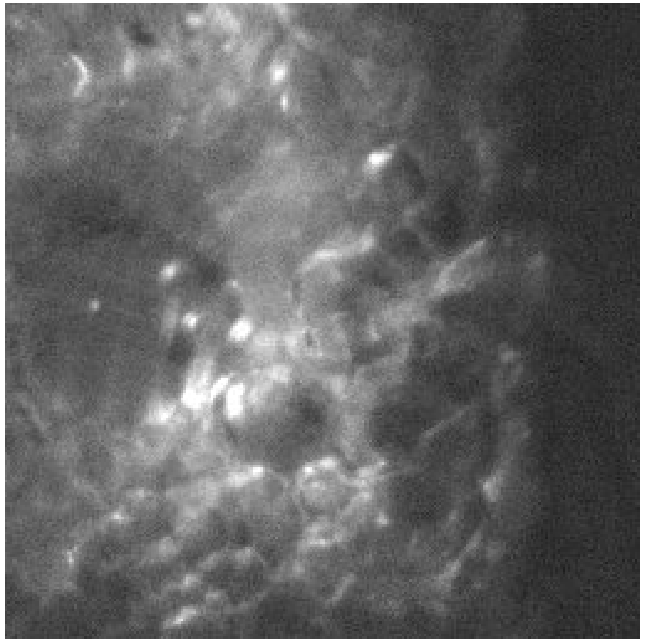


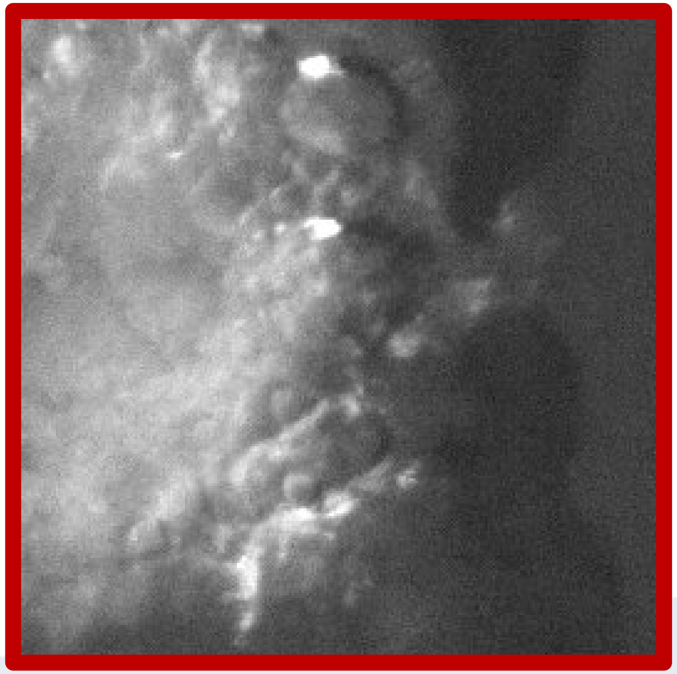
360 V

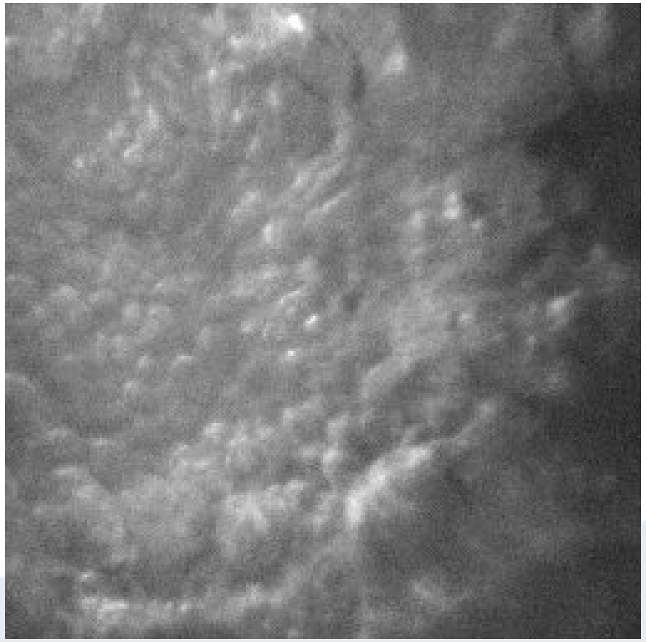
Investigation of plasma-electrolytic polishing (PeP) process initiation

SAMPLE 2 / PROCESS START

→ t = 4,17 ms



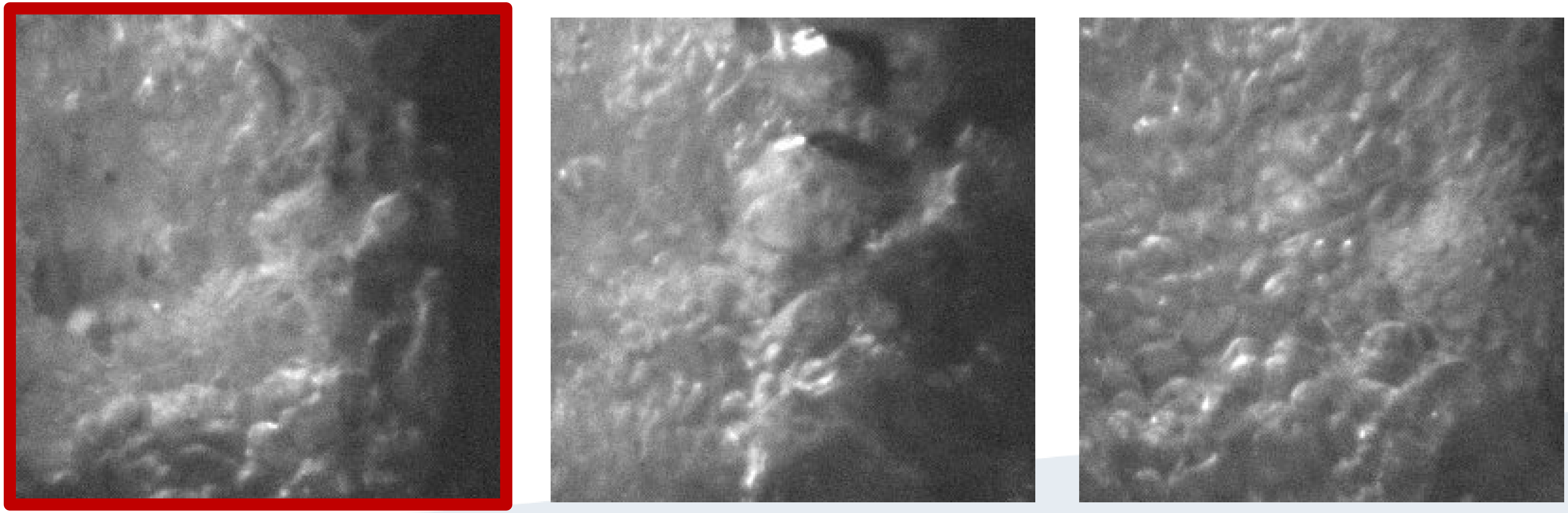




Investigation of plasma-electrolytic polishing (PeP) process initiation

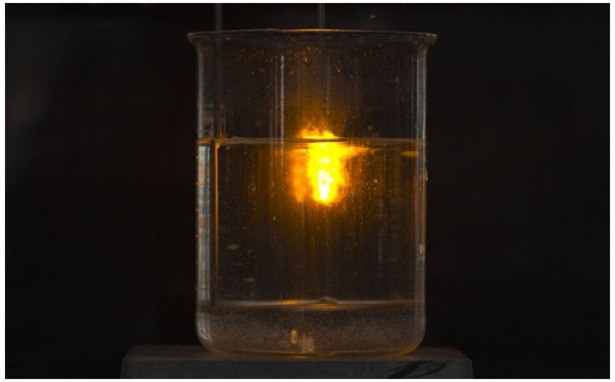
SAMPLE 2 / PROCESS START

→ t = 5,0 ms



PeP BENEFITS

- Low or no necessity for pre-treatment
- No shaped electrode / tool necessary
- Complex geometries polishable
- Small achievable roughness
  ($R_a \approx 0.02 \mu m$, depending on original roughness)
- Short polishing time
  (MRR ≥ 50 µm/min achievable)
- Improved surface gloss
  (MRR ≤ 5 µm/min)
- Environmentally harmless electrolytes
  of low concentration
- No adsorbates in the processed surface layer



PeP LIMITATIONS

- Electrically conductive parts required
- Suitable for finish polishing and burr removal, but unsuitable for one-step polishing of very rough surfaces and heavy burrs (edge rounding after long processing time)
- Process energy source determines maximum part size
- Treating internal cavities of high aspect ratio is difficult
- Electrolyte adaption for each alloy necessary

COMPARISON TO OTHER NON-CONVENTIONAL PROCESSES

Characteristic	EDM	ECM	PeP
Voltage [V]	75-400	<60	180-400+
Electrode distance [mm]	0.005-0.5	0.015-1	5-500
Workpiece polarity	Anode or Cathode	Anode	Anode
Conductive electrolyte	No (dielectric)	Yes	Yes
Creation of glossy surface	No	Depending on parameters	(Yes)
Workpiece-specific tool	(Yes)	(Yes)	No

AM PART PEP

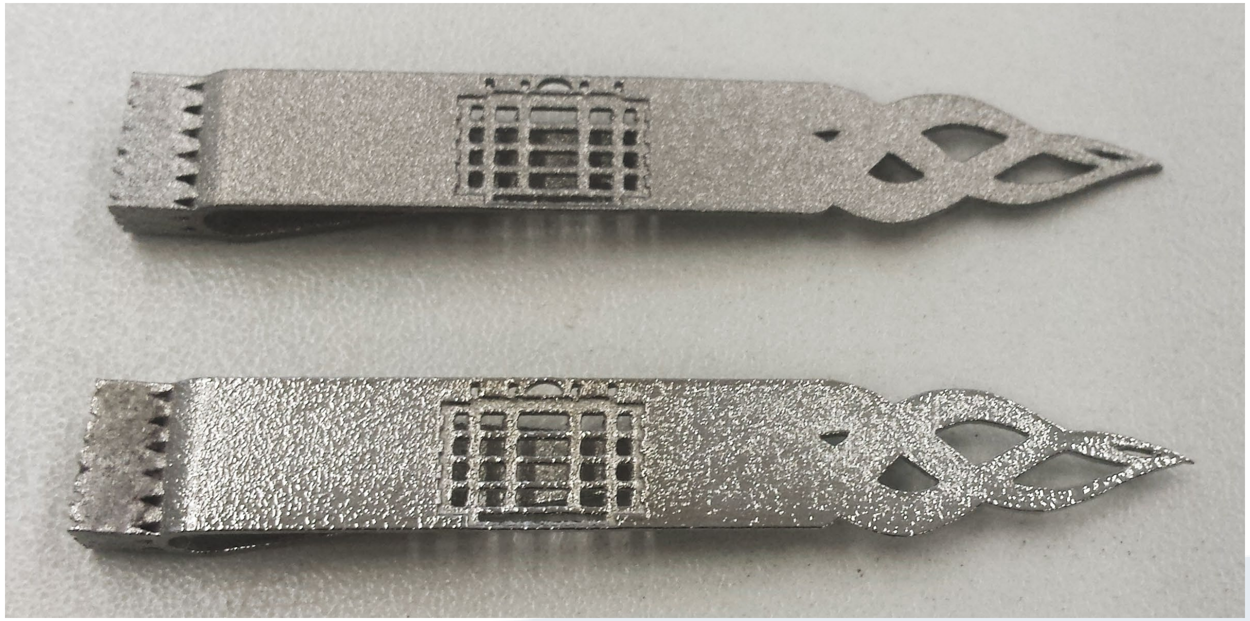
AM (PBF-LB/M) part

Material: Ti6Al4V

Target: gloss and shine increase

Pre-treatment: corundum blasting

- Gloss enhancement
- Build step visibility



APPLICATION: AM PARTS

AM (PBF-LB/M) part

Material: steel

Target: smooth surface, gloss and shine increase

Pre-treatment: corundum blasting

- Gloss enhancement and roughness decrease
- Reduction of built step visibility

AM PePe

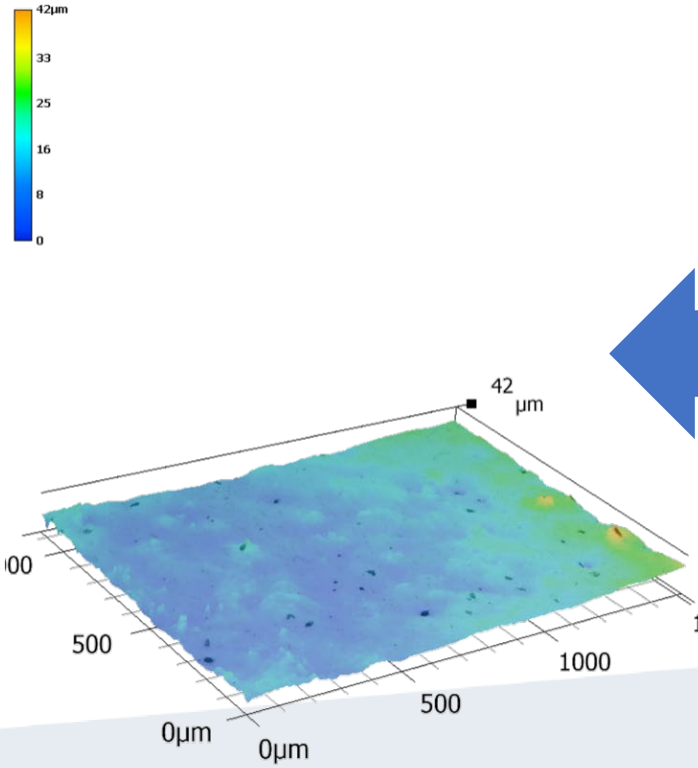
AM (PBF-LB/M) part

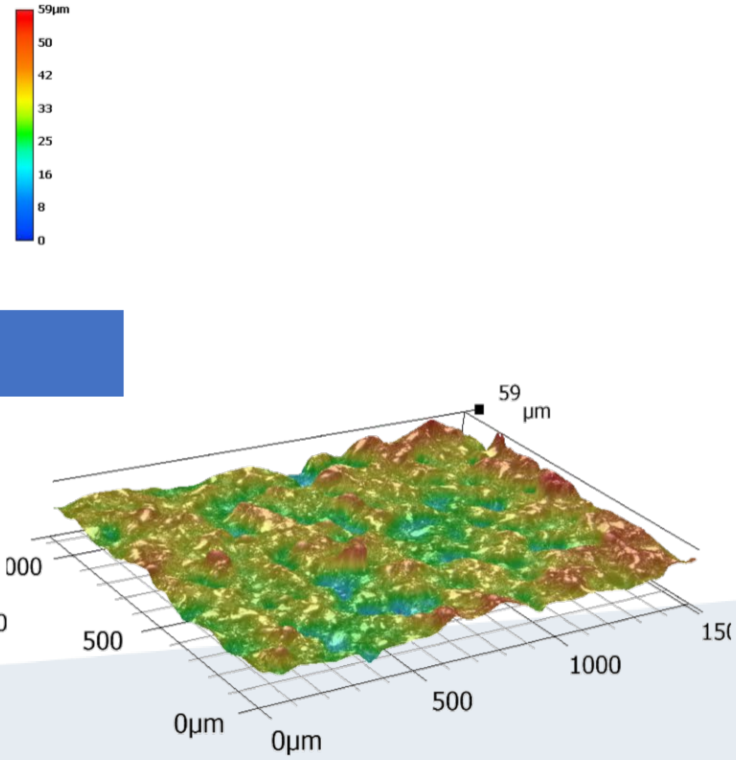
Material: steel

Polishing time 40min.

Pre-treatment: nil

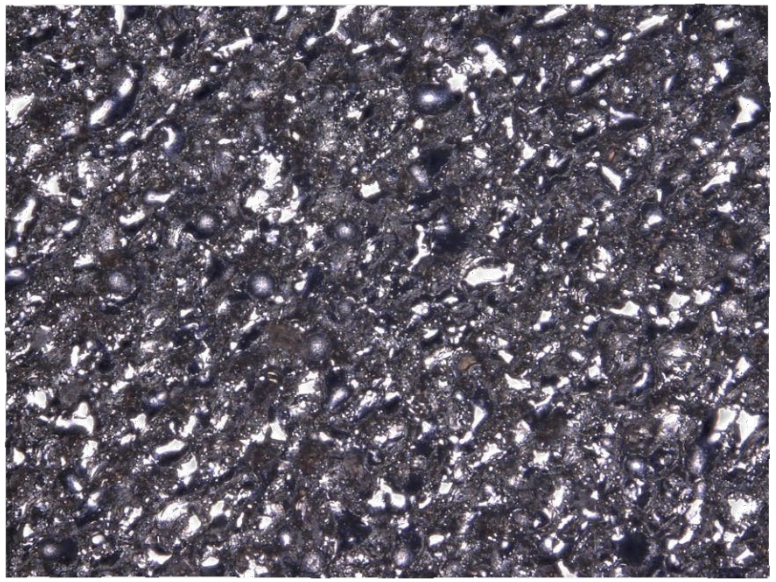
> Gloss enhancement and roughness decrease
> Reduction of built step visibility

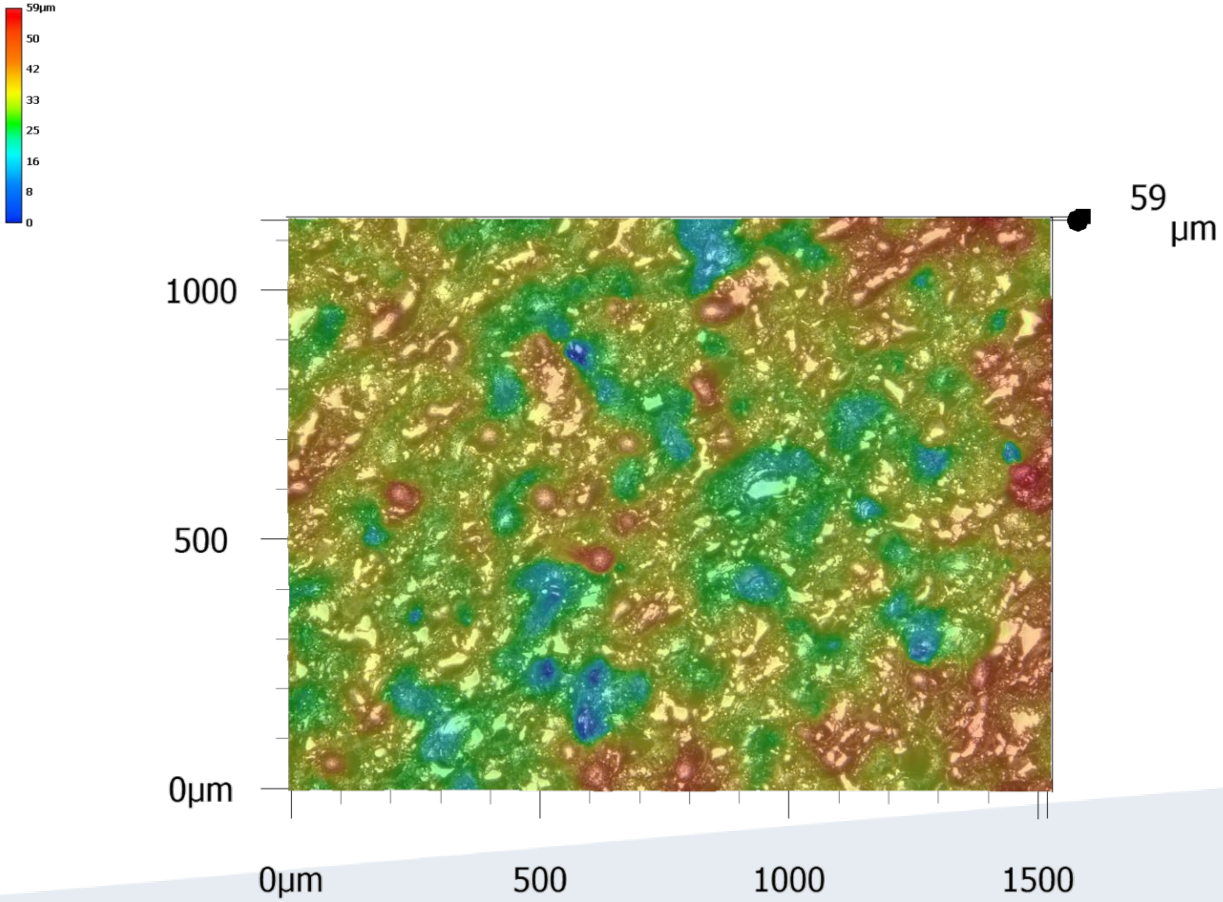




AM PeP

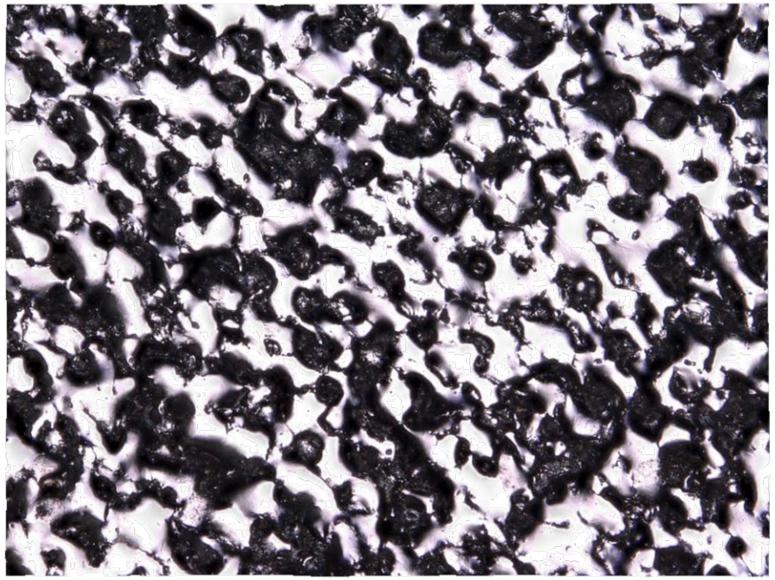
Steel PBF-LB/M part, 2min. PeP

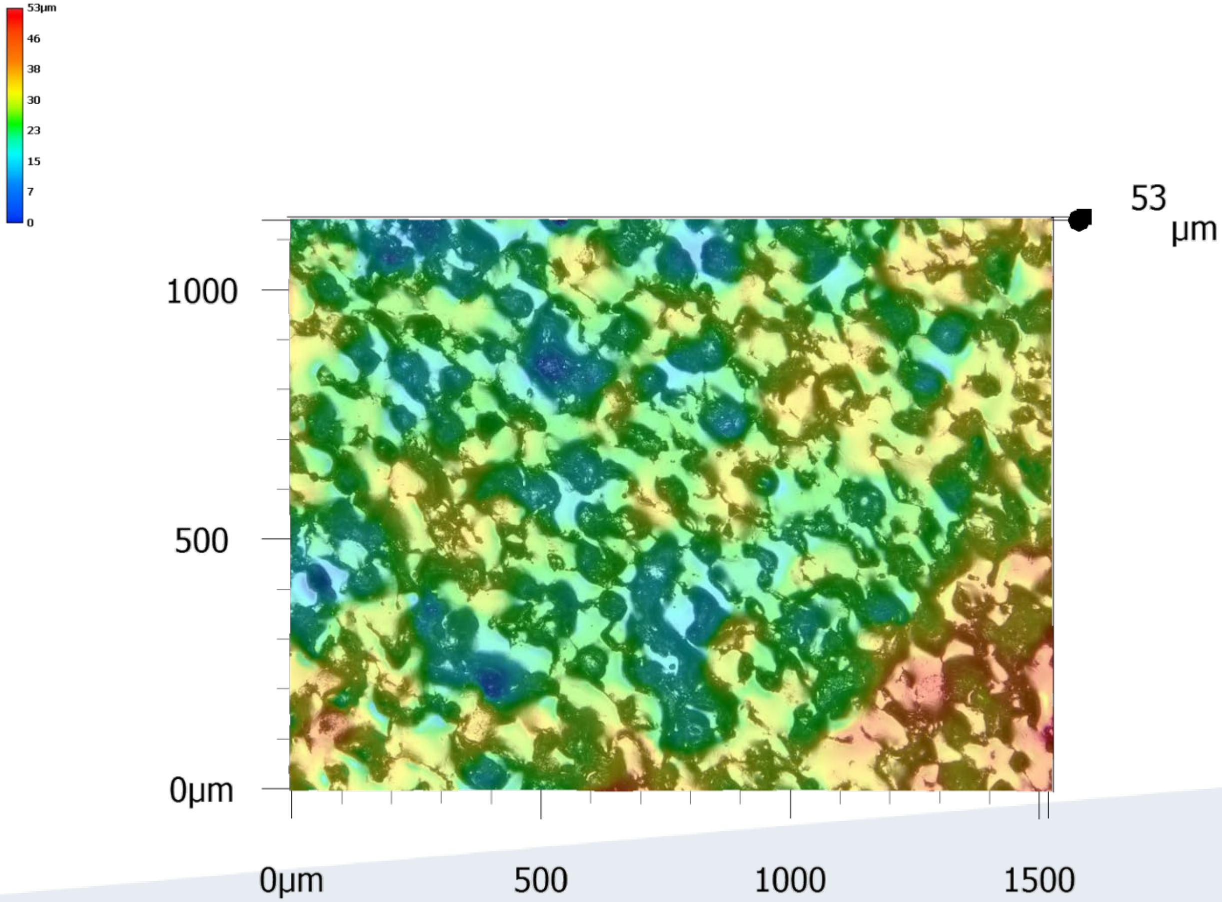




AM PeP

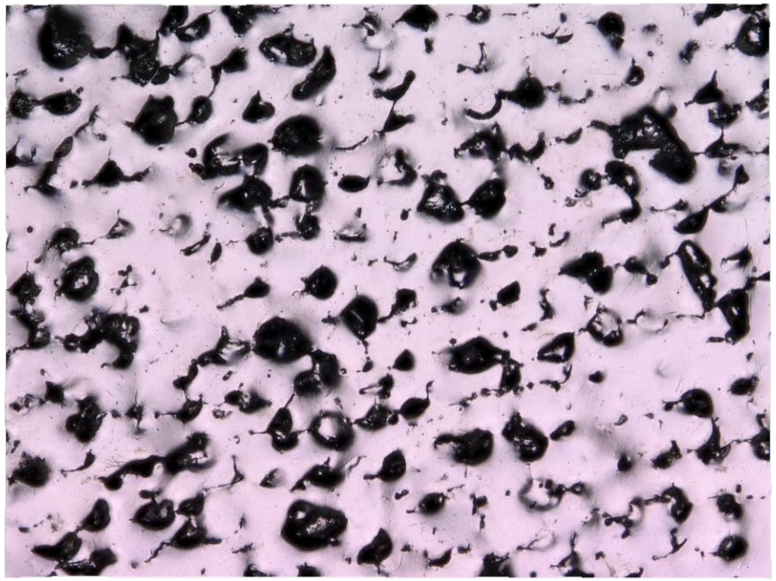
Steel PBF-LB/M part, 8 min. PeP

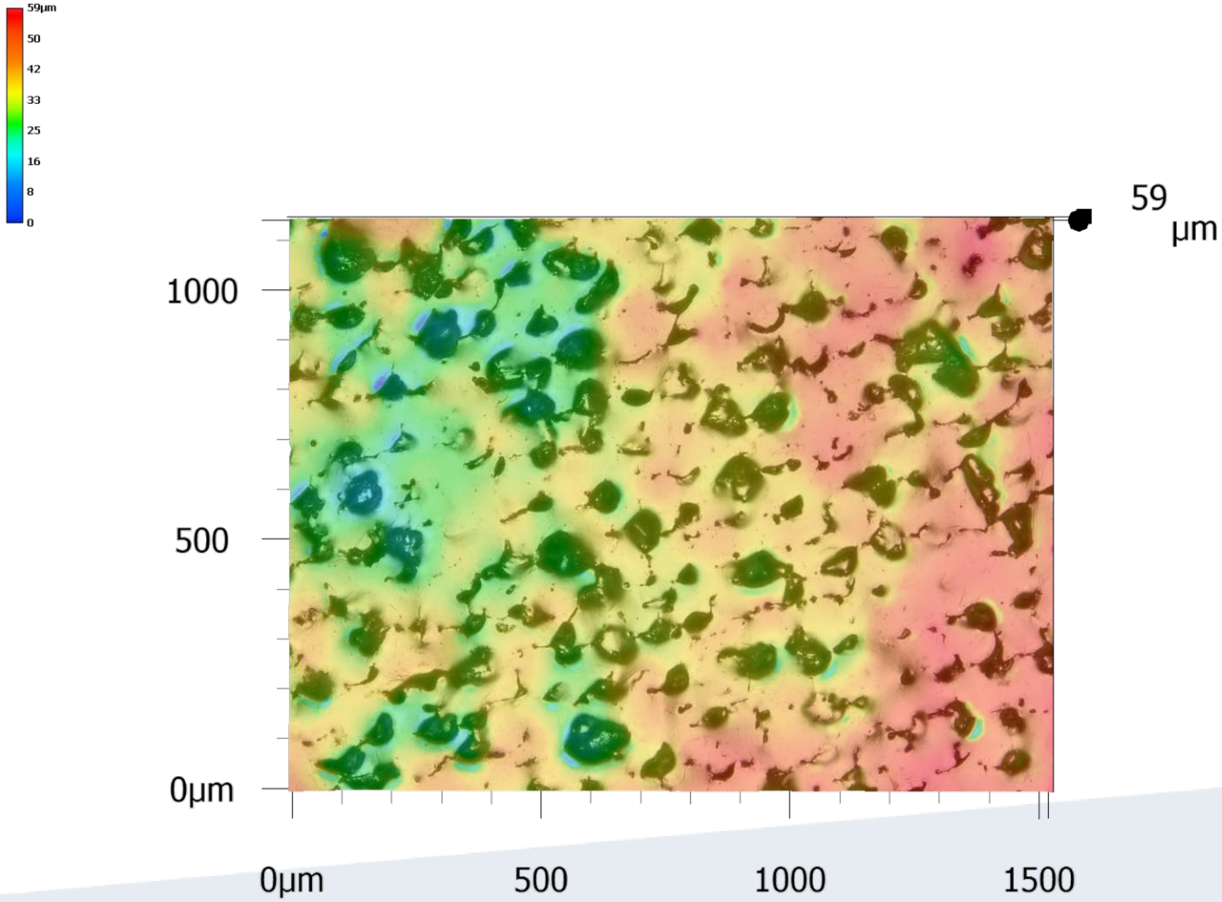




AM PeP

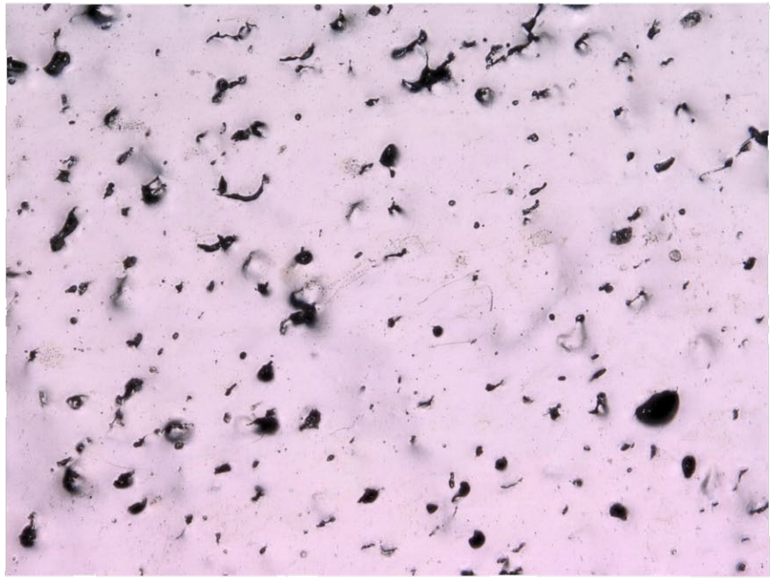
Steel PBF-LB/M part, 16 min. PeP

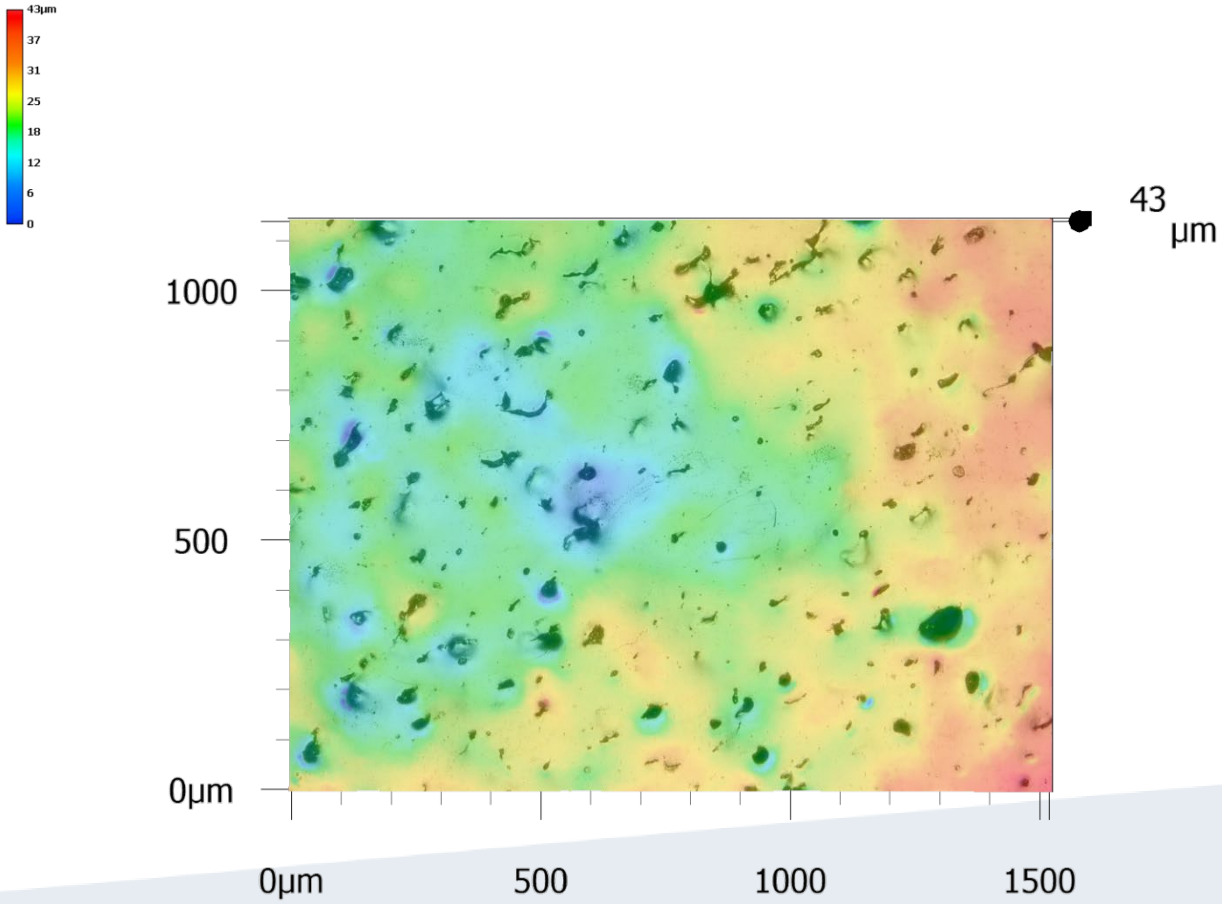




AM PeP

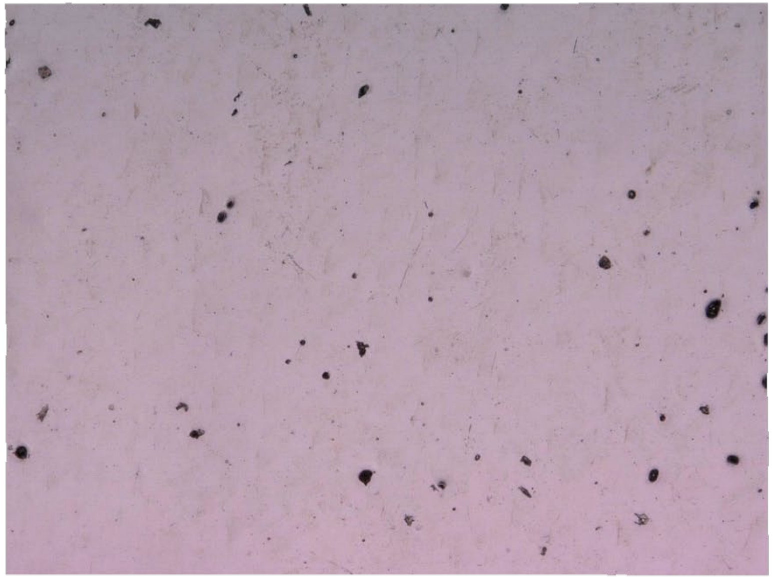
Steel PBF-LB/M part, 30 min. PeP

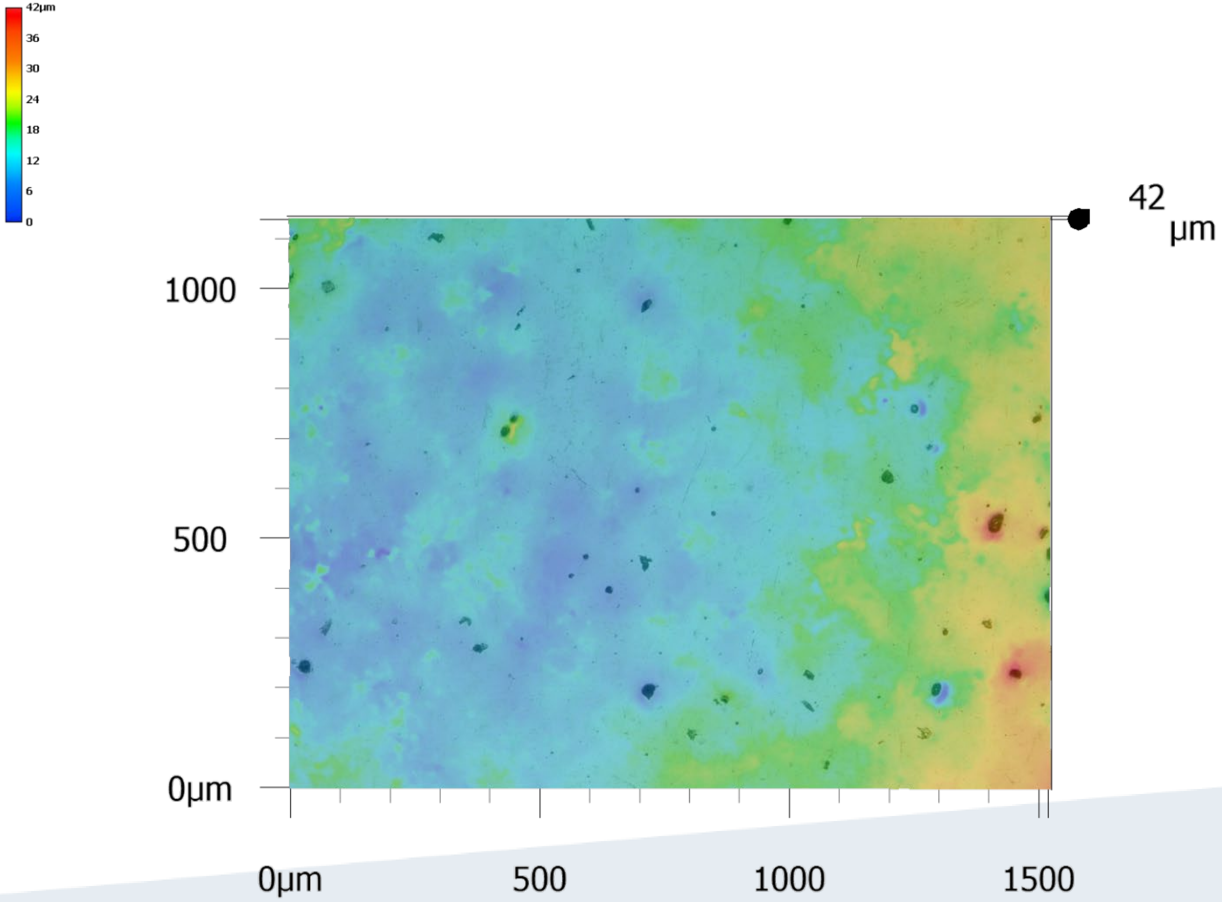




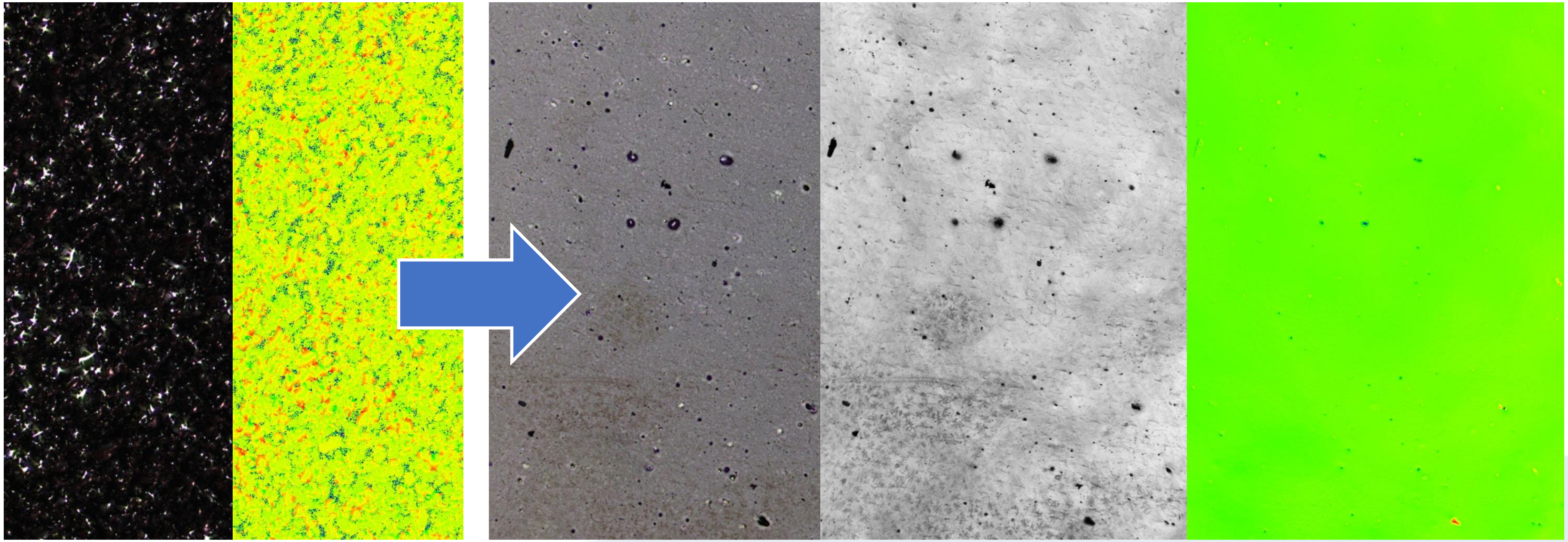
AM PeP

Steel PBF-LB/M part, 40 min. PeP



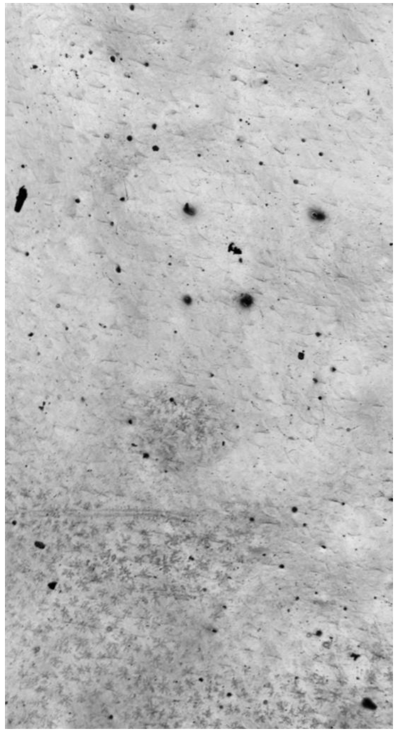


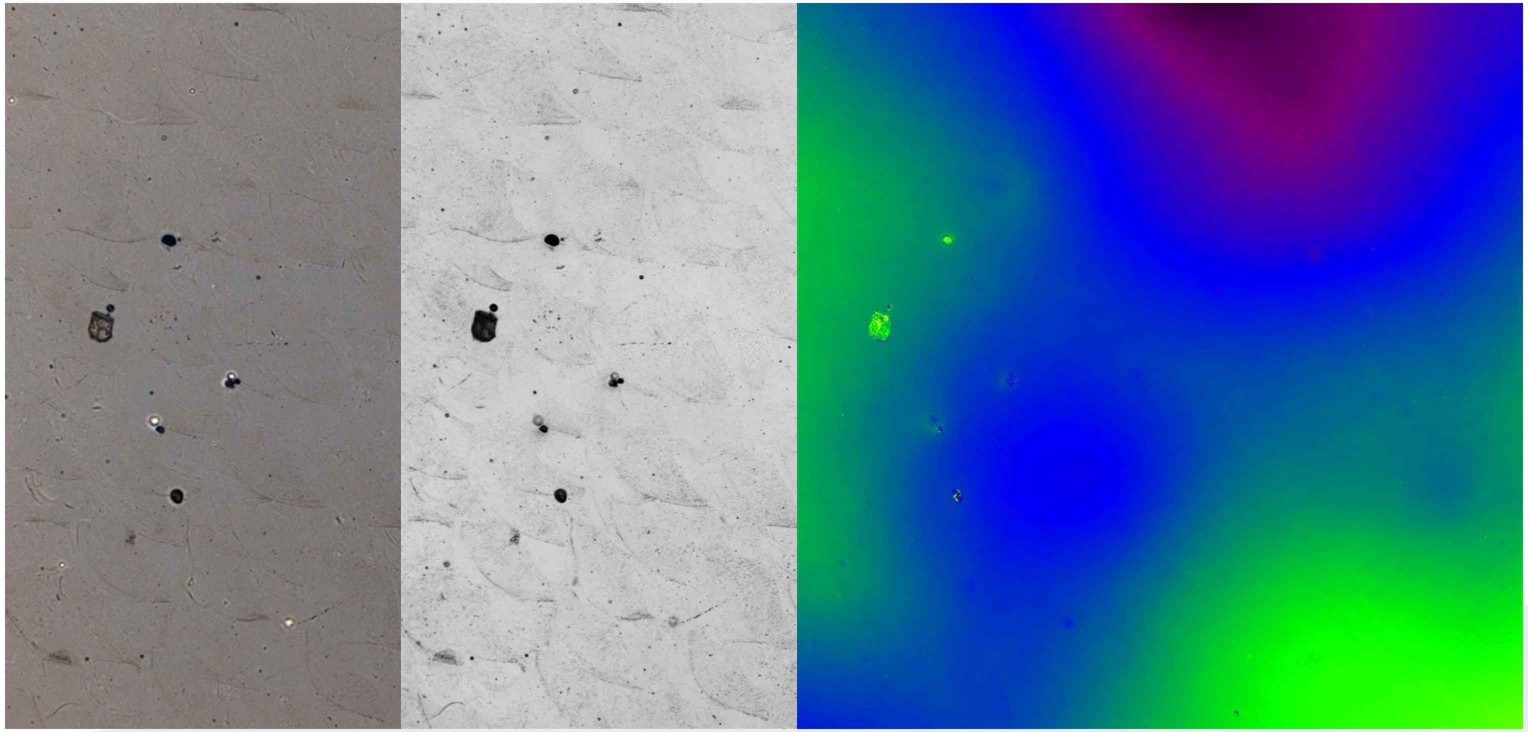
AM PeP



Steel PBF-LB/M part, 2min/30min PeP, LEXT imaging

AM PeP

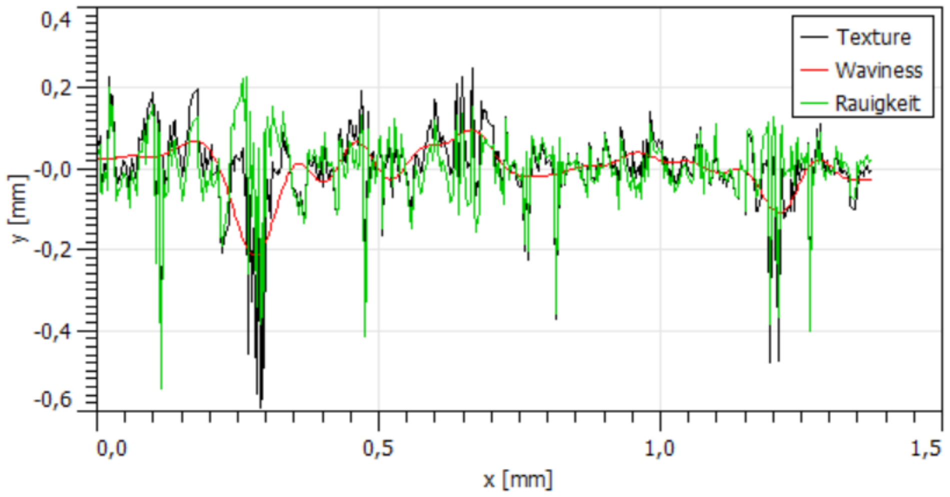




Steel PBF-LB/M part, 30min PeP, LEXT imaging (right side: higher magnification)

AM PePPeP

	Amplitude	
R_a	Roughness average	58,81 µm
R_q	Root mean square roughness	87,37 µm
R_t	Maximum height of the roughness	773,4 µm
R_v	Maximum roughness valley depth	547,9 µm
R_p	Maximum roughness peak height	225,4 µm
R_{tm}	Average maximum height of the roughness	520,8 µm
R_{vm}	Average maximum roughness valley depth	368,6 µm
R_{pm}	Average maximum roughness peak height	152,2 µm
R_{3z}	Average third highest peak to third lowest valley height	563,5 µm
$R_{3z\ ISO}$	Average third highest peak to third lowest valley height	365,4 µm



Steel PBF-LB/M part,

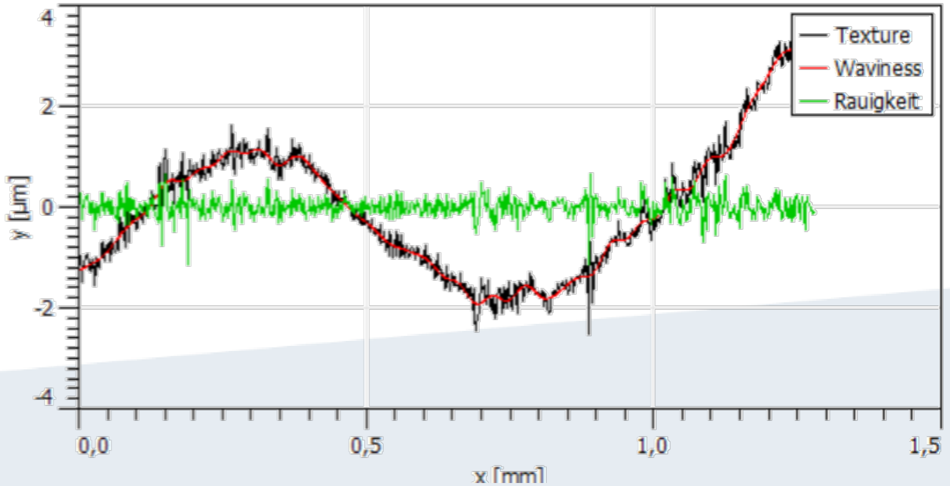
2min/30min PeP,

LEXT imaging,

gwyddion analysis

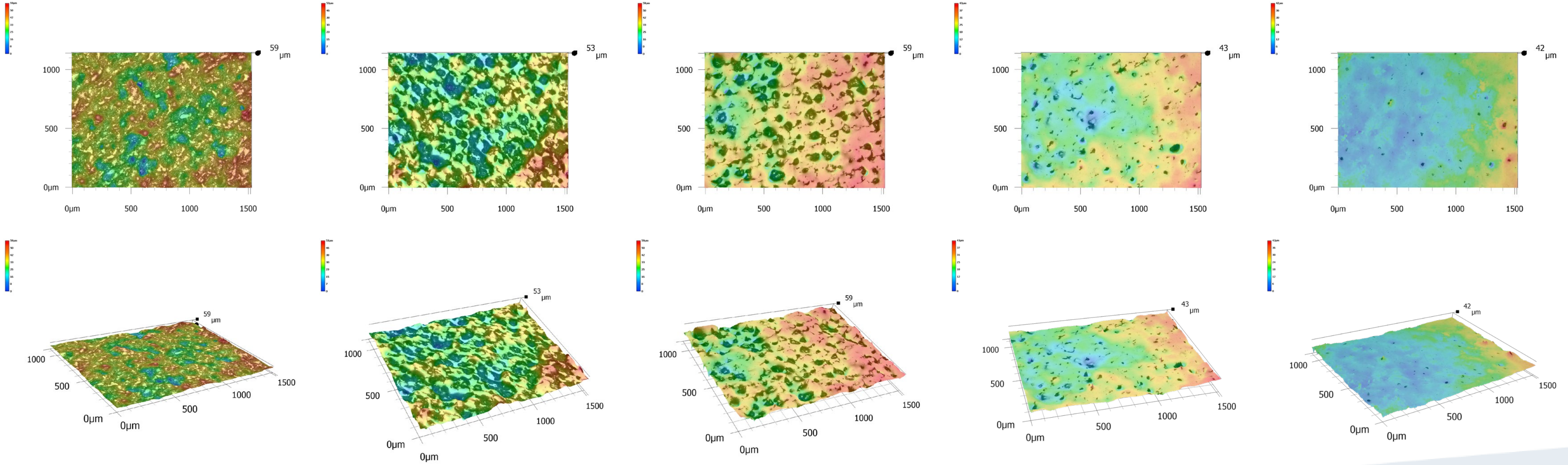
Careful: not acquired according to standards!

	Amplitude	
R_a	Roughness average	131,0 nm
R_q	Root mean square roughness	181,5 nm
R_t	Maximum height of the roughness	1,845 µm
R_v	Maximum roughness valley depth	1,179 µm
R_p	Maximum roughness peak height	665,8 nm
R_{tm}	Average maximum height of the roughness	1,413 µm
R_{vm}	Average maximum roughness valley depth	822,0 nm
R_{pm}	Average maximum roughness peak height	590,8 nm
R_{3z}	Average third highest peak to third lowest valley height	1,379 µm
$R_{3z\ ISO}$	Average third highest peak to third lowest valley height	803,2 nm

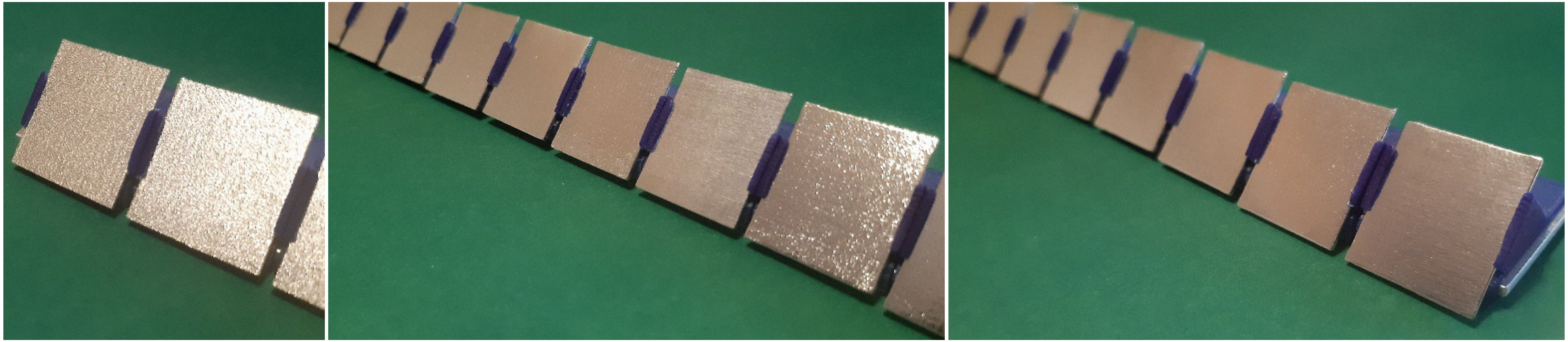


AM PeP

Steel PBF-LB/M part, 2-40 min. PeP



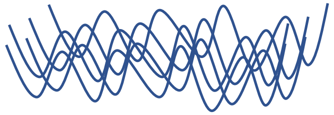
SURFACE PROGRESSION

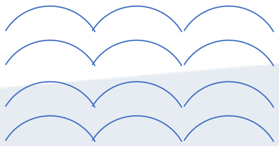


Steel PBF-LB/M part, 0/2min 8/10/12/14min 18/20/25/30min PeP, optical imaging

AM SURFACE CHARACTERISTICS

Powder based		Wire based
Fine	Layer thickness	Coarse
Flat/straight	Layer border shape	Rounded
Partially molten material, adhesion of powder	Influencing factors	Flow rate, pores, composition
High frequency 2D roughness	Perception	Low frequency 1D waviness





PeP SPECIFIC PROPERTIES

	Low removal	Medium removal	Large removal	
Gloss	+++	+++	+++	Material specific
Roughness (micro)	+++	+++	+++	Self-focus on sharp peaks
Waviness	++	+	+/-	Slow removal of high kinematic roughness
Accuracy	+++	++	+/-	Edge rounding
Toxicity	+++	+++	+++	No cytotoxicity
Planarity	++	+/-	+/-	Influence of fluid/gas flow
Cleanliness	+++	+++	+++	No adsorbates

APPLICATION: CORROSION INHIBITION

Copper medtech part

Material: copper

Target: surface corroding less fast

Pre-treatment: nil

- Decrease in oxidation speed
- Salt spray test supports slower corrosion statement

© BTE

APPLICATION: MEDICAL

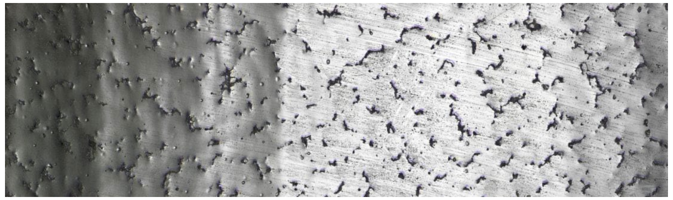
Implant part

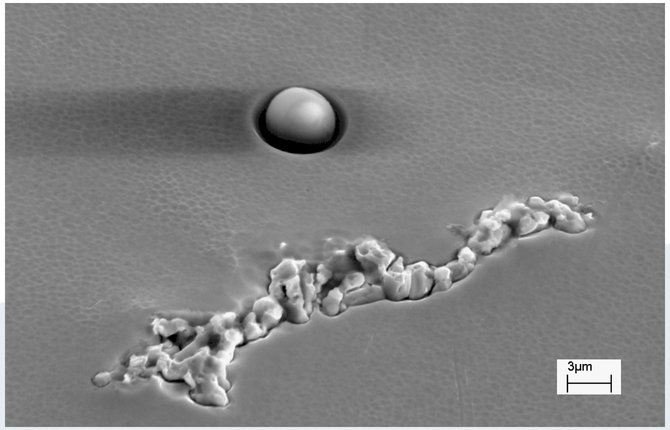
Material: CoCr

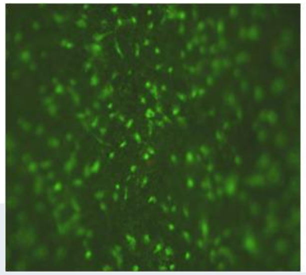
Target: deburring, surface smoothing, biocompatible

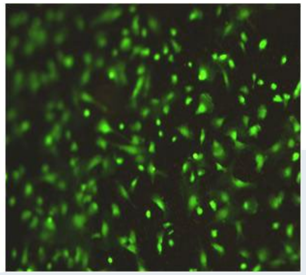
Pre-treatment: fine machining / cutting

- Smoothing depending on *real* material composition
- No cytotoxicity based on process
- Bacteria growth inhibited







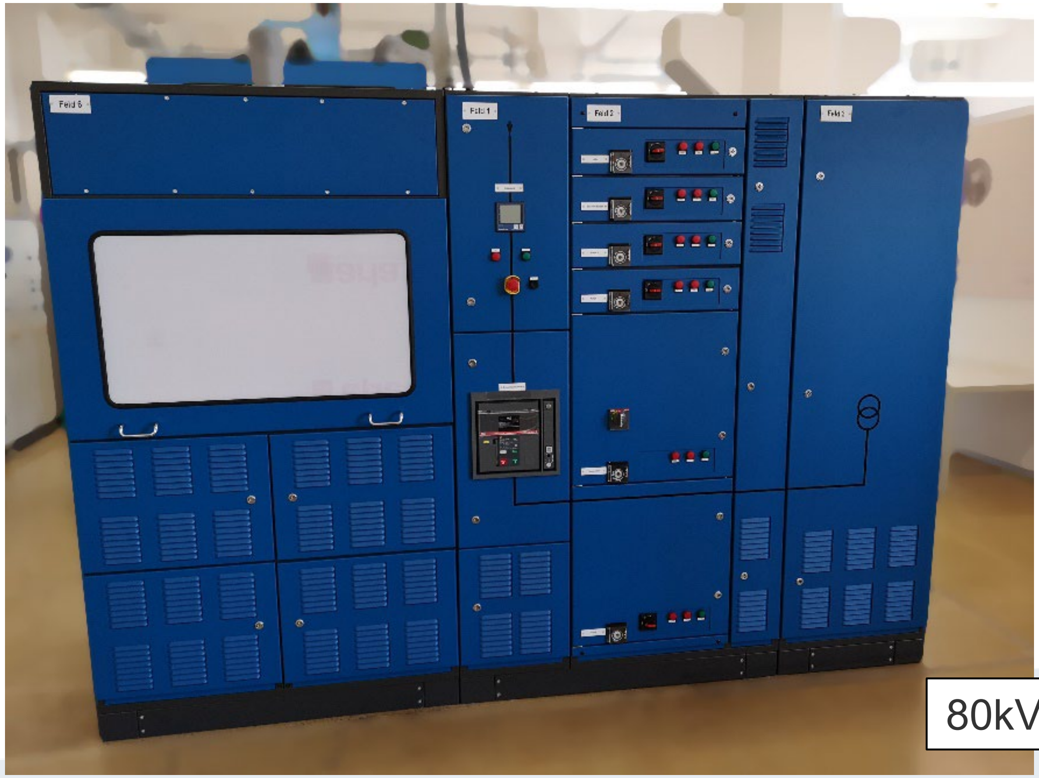


TASK TO SOLVE FOR INDUSTRIAL UPTAKE

Material composition	Large surface areas	Suitable roughness range	Process chain integration
• Material composition needs to be exactly known • Electrolyte needs specific adaption	• Constant parameters over large areas • Direct influence on required power • Request for selective polishing • Different initial states	• Parameter range input/output • Assessment of efficiency, time, cost	• Handling and automatisation of parts • Cross-machine communication • Online quality control and parameter setting
Database generation	Selective/Jet-PeP	Fundamental research	Pilot plant

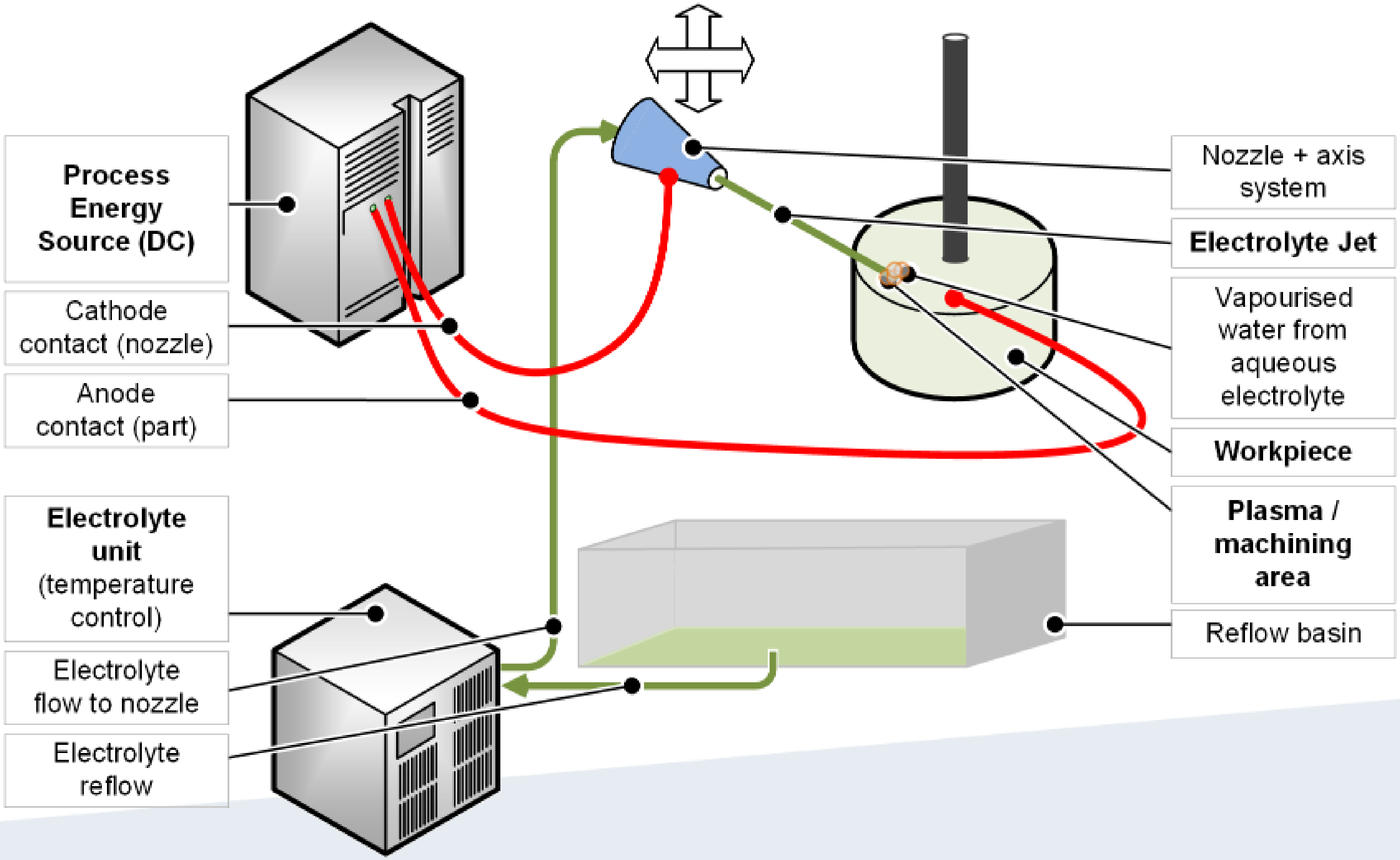
EQUIPMENT: VAT PeP

4kVA flex PES



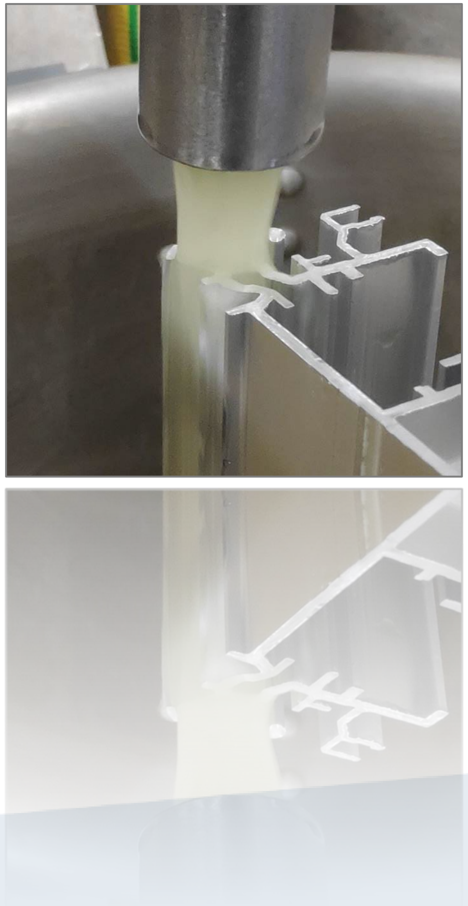
80kVA PeP setup

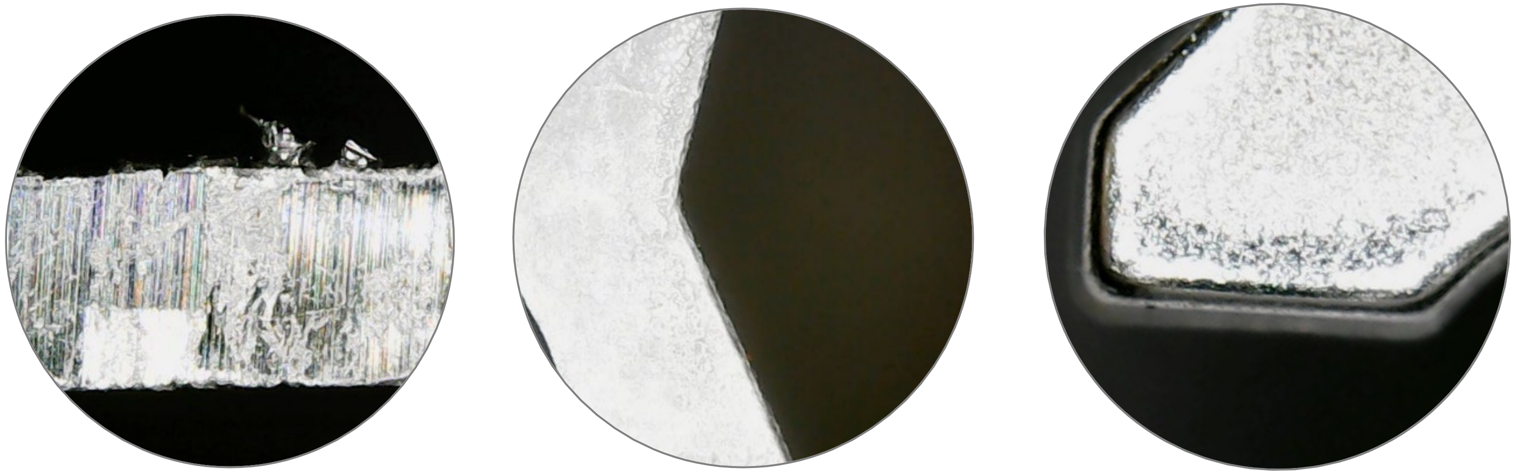
JET-PEP PROCESS PRINCIPLE



Plasma assisted surface treatment of additively manufactured parts

LOCAL TREATMENT USING JET-PEP





untreated 15s 60s

- Selective deburring and polishing
- Robot-driven kinematics

JETPEP

JETPEP makes processing possible that could previously only be done manually.

18 s JETPEP

Applications

- Polishing of large workpieces (up to continuous)
- Area-specific reduction of roughness
- Targeted post-processing of weld seams

JETPEP

JETPEP breaks through the application limits of plasma polishing: part size and selectivity.

Process

- Plasma polishing: approx. 70 W/cm²
- Selective and jet-based processing by means of a special JETPEP nozzle
- Low flow velocities, localized finishing effect
- Automation via robot and axis kinematics

The unique properties of plasma-polished surfaces – exactly where you need them.

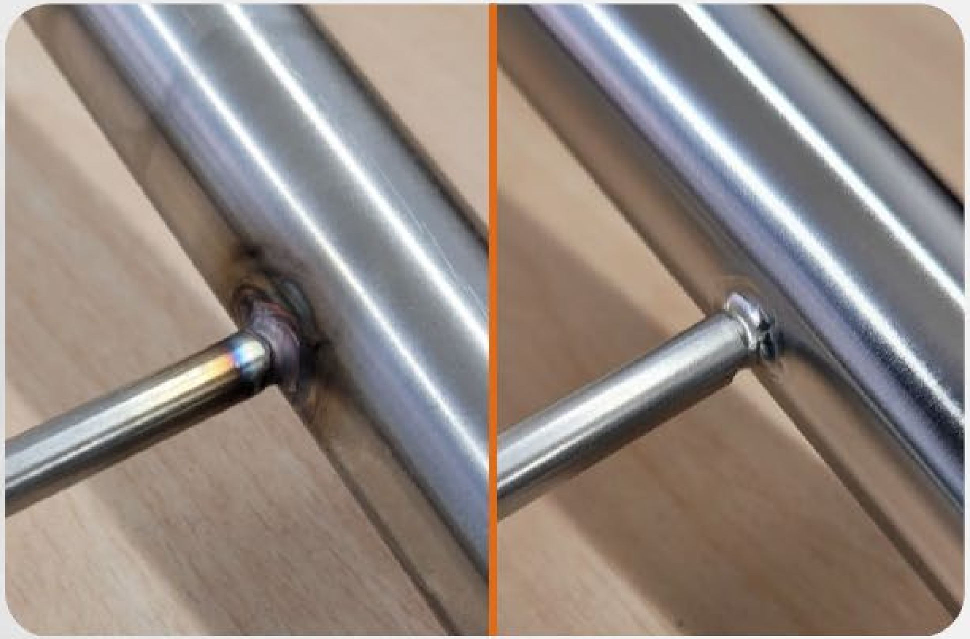
W
Al
Fe
Cu
Ti
Ni
Co
...

Welded assembly for the food industry

Material: 1.4301

Challenge: Local post-processing of welds, homogeneous gloss

Result: Removal of welding fumes and tarnishes within 15 s, increased gloss on the base surface



Schweißbaugruppe aus 1.4301, vor und nach dem JETPEP

SUMMARY

- ➲ PeP of post-processed AM parts
  - ➲ Roughness reduction
  - ➲ Gloss increase
- ➲ AM parameters can be traced with PeP
  - ➲ Scanning/hatching strategy
- ➲ Opening of pores
  - ➲ No „hiding“ of faulty parts
  - ➲ Possible deterioration of „optically viable“ surfaces

CONTACT

Technische Universität Bergakademie Freiberg

IMKF - Additive Manufacturing

Agricolastraße 1, 09599 Freiberg, Germany

Prof. Dr.-Ing. Henning Zeidler

Tel: +49 3731 39 30 66

henning.zeidler@imkf.tu-freiberg.de