Fundamentals of Simultaneous Machining and Coating (SMaC)

Combination of extreme high-speed laser material deposition (EHLA) and turning

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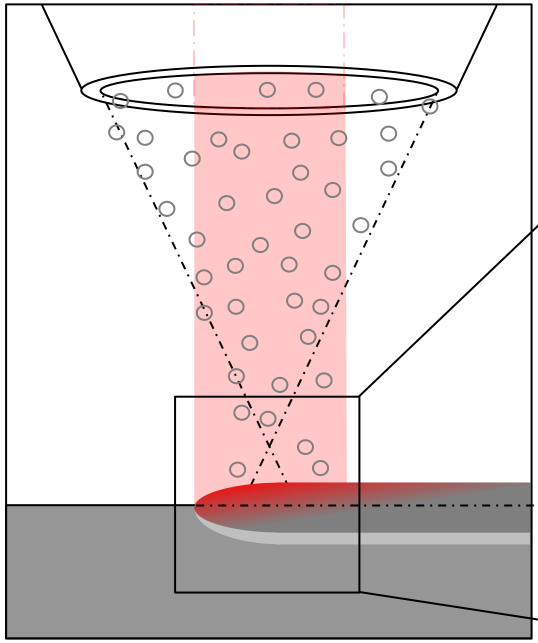
Fundamentals of Simultaneous Machining and Coating (SMaC)

Index

What is EHLA?

EHLA – Extreme High-Speed Laser Material Deposition



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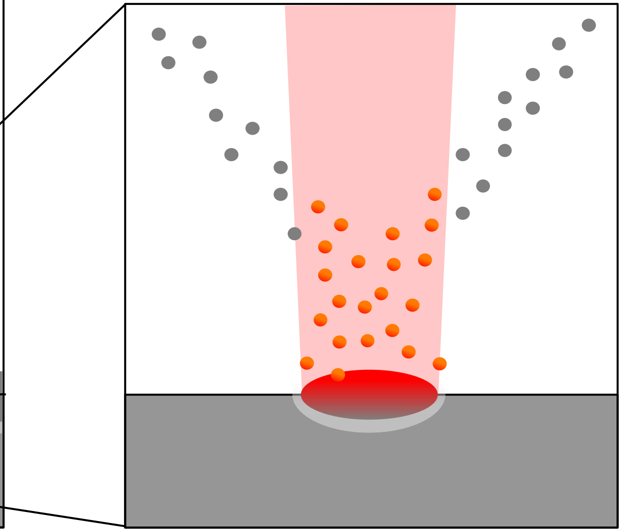
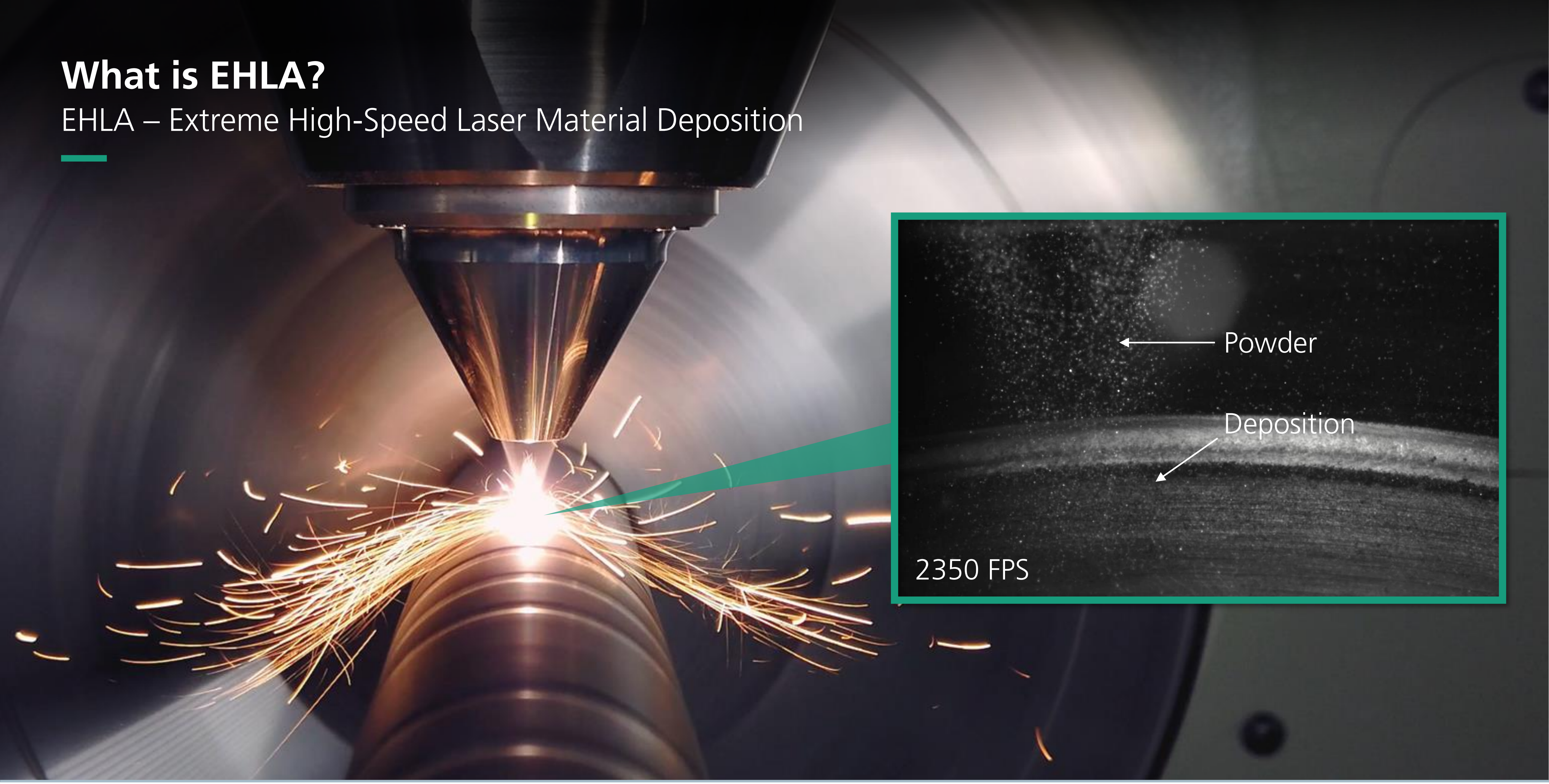


- **High-speed** variant of LMD (>>20 m/min)
- Powder is melting **above** the workpiece surface
- Powder **material efficiency >90%**
- Low dilution, heat affected zone and distortion
- Layer thickness between 30 µm and 500 µm
- Industrial applications in **Coating, Repair and AM**
- Known as HS-LMD, HSLC, UHSLC, HS-DED, RC, …

What is EHLA?

EHLA – Extreme High-Speed Laser Material Deposition



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EHLA coating applications and surface quality requirements

EHLA – Extreme High-Speed Laser Material Deposition

EHLA coating

Typical surface roughness:
Ra 4.6 – 20.5 µm

Post-machining

- Turning
- Grinding
- Milling
- Roller burnishing
- …

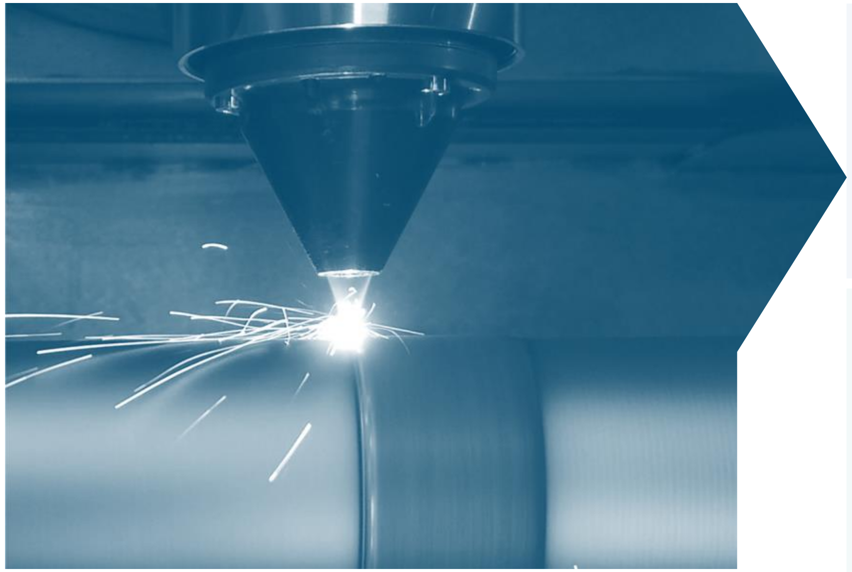
Industrial application

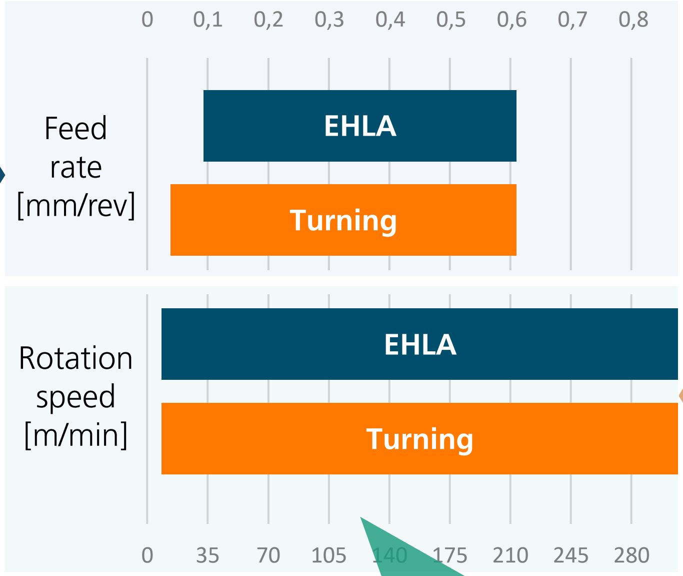
- Automotive (brake disc rotors, piston rods, …)
- Aerospace (Landing gear components)
- Agricultural (harvester knives, circular blades)
- Energy (wind power drives, offshore)
- Manufacturing (cylinders, rollers)

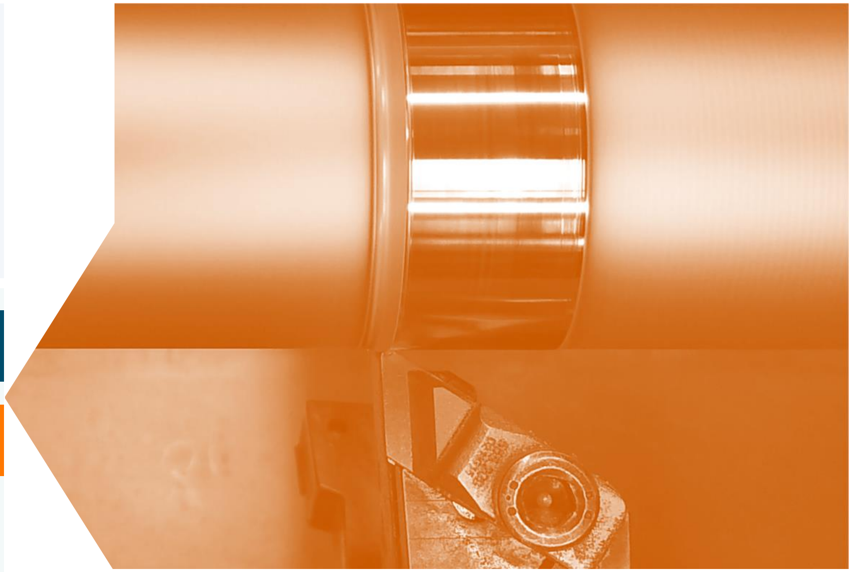
Typical requirements for functional surfaces:
Ra 0.4 – 1.6 µm

What is SMaC?

Fundamentals of Simultaneous Machining and Coating (SMaC)







Coating via EHLA

Typical surface speeds (spindle rotation):
20 m/min – 500 m/min

Typical feed rates (axial movement):
0.1 mm/rev – 0.6 mm/rev

Process parameters of EHLA and turning are largely congruent!

Post-machining via turning

Typical cutting speeds (spindle rotation):
20 m/min – 600 m/min

Typical feed rates (axial movement):
0.05 – 0.6 mm/rev

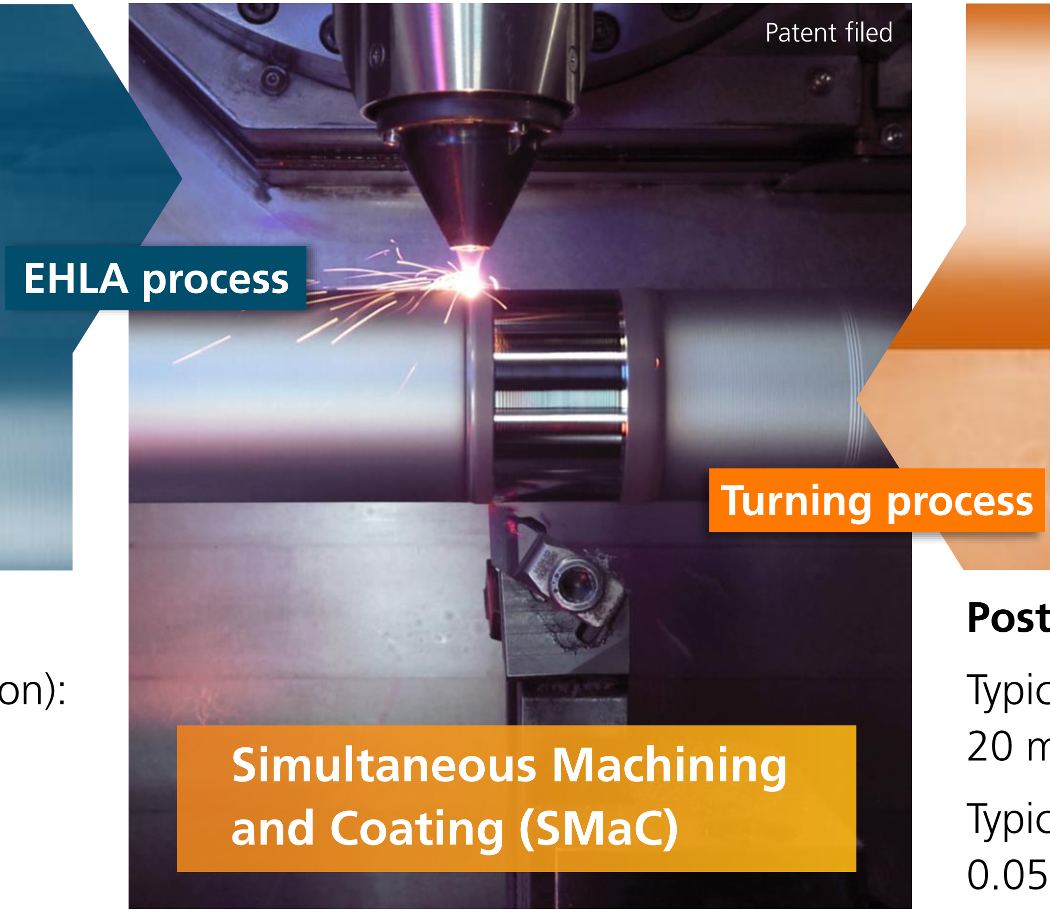
What is SMaC?

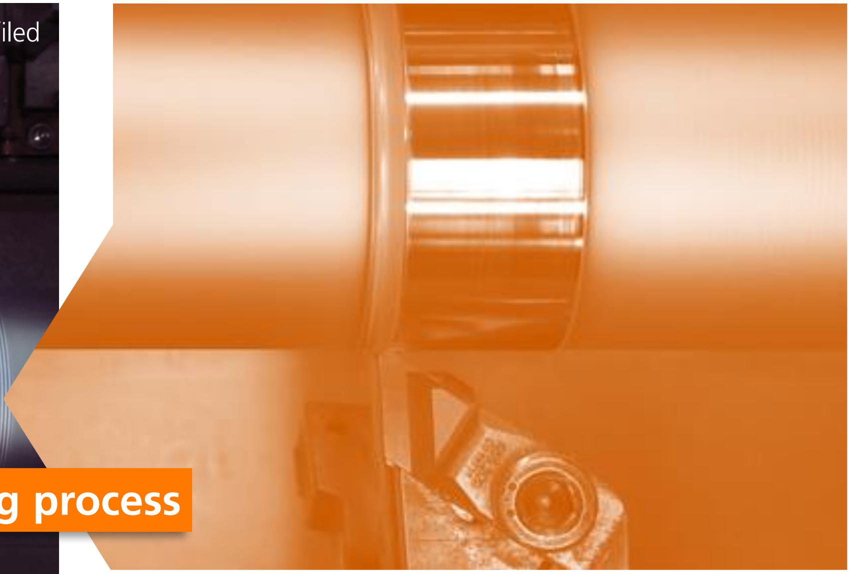
Fundamentals of Simultaneous Machining and Coating (SMaC)

Coating via EHLA

Typical surface speeds (spindle rotation):
20 m/min – 500 m/min

Typical feed rates (axial movement):
0.1 mm/rev – 0.6 mm/rev





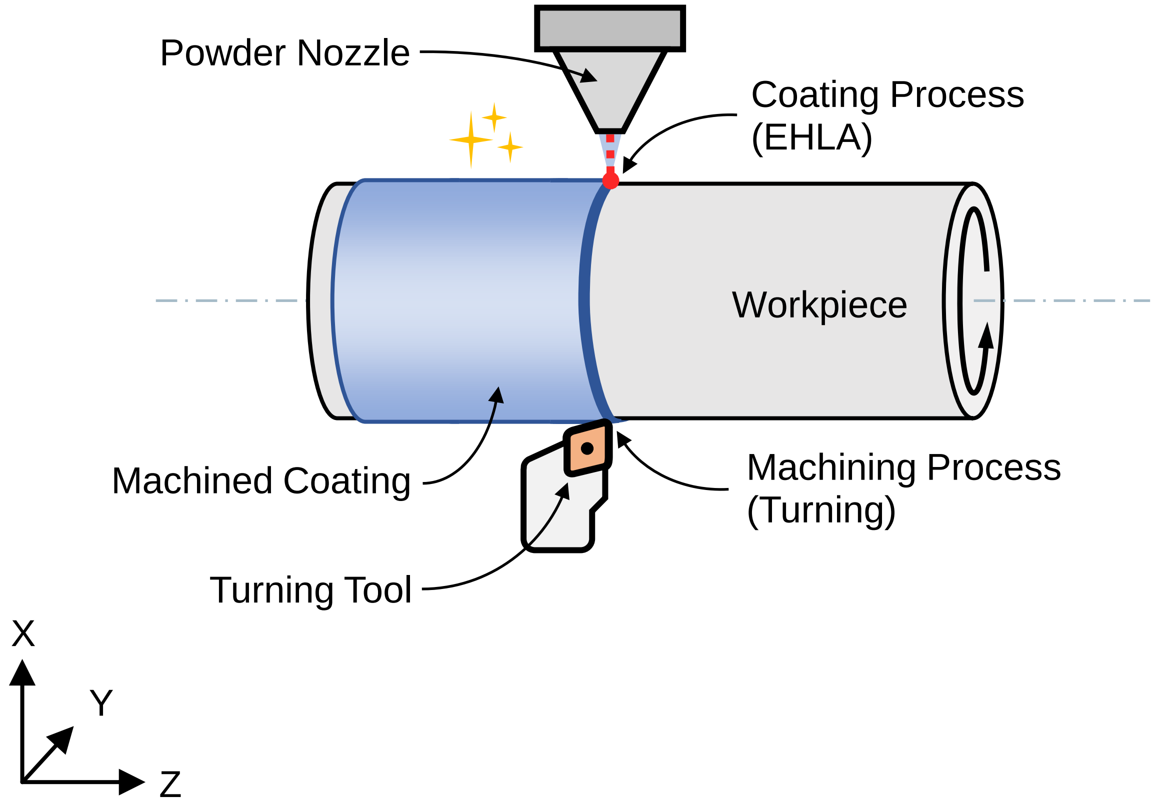
Post-machining via turning

Typical cutting speeds (spindle rotation):
20 m/min – 600 m/min

Typical feed rates (axial movement):
0.05 – 0.6

Operating principle and relevant parameters

Fundamentals of Simultaneous Machining and Coating (SMaC)



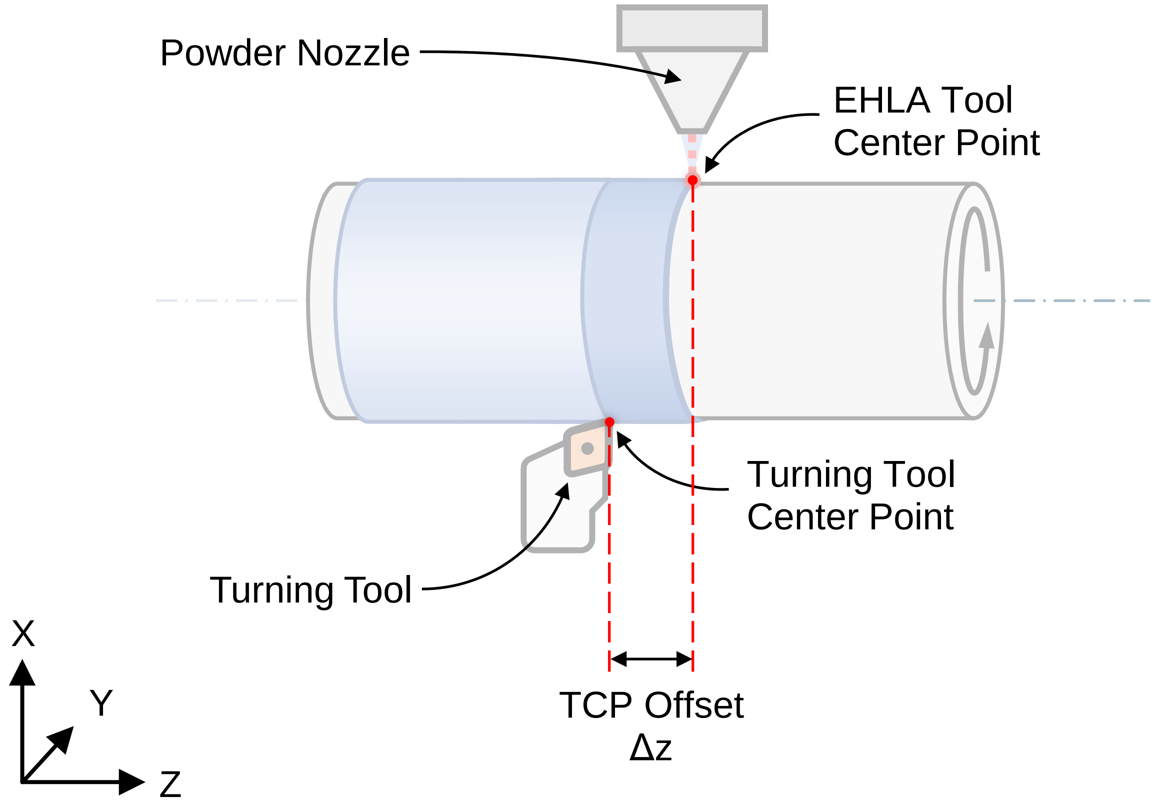
SMaC process parameters

● (coating)	Laser power	[W]
● (coating)	Laser spot diameter	[mm]
●● (machining, coating)	Surface speed	[m/min]
●● (machining, coating)	Feed rate	[mm/rev]
● (coating)	Powder mass flow	[kg/h]
● (coating)	Shielding gas flow	[l/min]
● (coating)	Carrier gas flow	[l/min]
● (machining)	Depth of cut	[mm]

- ● Parameter related to the machining process
- ● Parameter related to the coating process

Operating principle and relevant parameters

Fundamentals of Simultaneous Machining and Coating (SMaC)



SMaC process parameters

●	Laser power	[W]
●	Laser spot diameter	[mm]
●●	Surface speed	[m/min]
●●	Feed rate	[mm/rev]
●	Powder mass flow	[kg/h]
●	Shielding gas flow	[l/min]
●	Carrier gas flow	[l/min]
●	Depth of cut	[mm]
●	TCP offset Δz	[mm]

In the focus of this work

- ● Parameter related to the machining process
- ● Parameter related to the coating process
- ● Parameter unique to the SMaC process

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Research question

Investigating the fundamentals of Simultaneous Machining and Coating (SMaC)

Which impact does simultaneous machining have on…

1. **dimensional accuracy**
2. **surface roughness**
3. **tool wear**

… in comparison to sequential machining?

Experimental setup and materials

Investigating the fundamentals of Simultaneous Machining and Coating (SMaC)

Coating process setup

Laser beam source:
Laserline LDF 8000-40
max. 8.7 kW Laser power
BPP 40 mm*mrad

Optics:
Laserline OTZ-5 Zoom Optics
400 µm fiber core diameter
Laser spot diameter 1.4 – 6 mm

Nozzle:
HD HighNo 4.0 (SO: 10 mm)

J.G. Weisser ARTERY M-2 Hybrid-EHLA

Substrate and powder material:

- AISI 4130 substrate rods, Ø50 mm
- Höganäs X-Rockit® 431 SR 20-53 martensitic stainless steel powder

Turning process setup

Workpiece handling:
max. 5400 RPM
max. 1000 mm length

Tool Turret:
12 live tool slots
BMT 65 tool holder

Turning tool inserts:
Sumitomo AC6030M
0.8 mm corner radius


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Experimental approach

Investigating the fundamentals of Simultaneous Machining and Coating (SMaC)

Investigation stage 1

EHLA process parameter development for X-Rockit 431 SR

- Target coating thickness: 200 µm each
- Var. A: 100 m/min, 0.15 mm/rev
  Var. B: 150 m/min, 0.15 mm/rev
- No cracks, minimal porosity, no bonding defects

Investigation stage 2

SMaC trials with variation of TCP offset Δz

- Coating/machining length:
  L = 15 mm
- Δz ∈ {2 mm, 3 mm, 5 mm,
  7 mm, 9 mm, 11mm}
- Unmachined and sequentially turned coatings as reference

Evaluation of **dimensional accuracy**

Evaluation of **surface roughness**

Investigation stage 3

Deposition of larger coating sections for tool wear assessment

- Coating/machining length:
  6 segments with L = 90 mm each
- Δz = 7 mm
- Sequentially turned coatings as reference

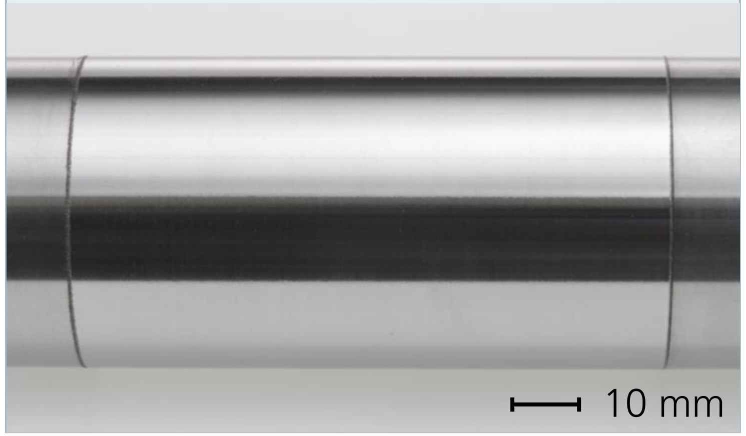
Evaluation of **tool wear**

Evaluation methodology

Investigating the fundamentals of Simultaneous Machining and Coating (SMaC)

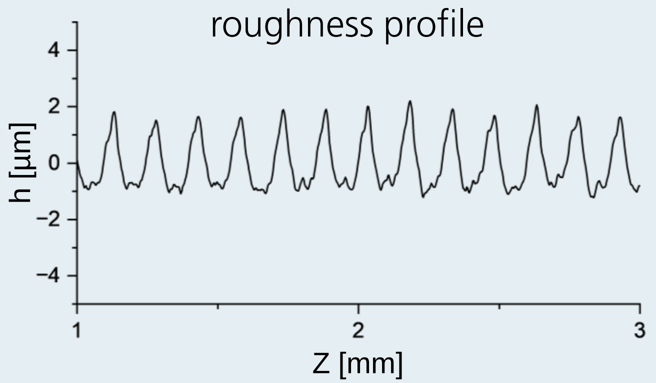
Dimensional deviations

- Surface measurement using Zygo Ametek NX2 WLI
- Extraction of **waviness** profiles according to DIN EN ISO 4287 and DIN EN ISO 4288:1998



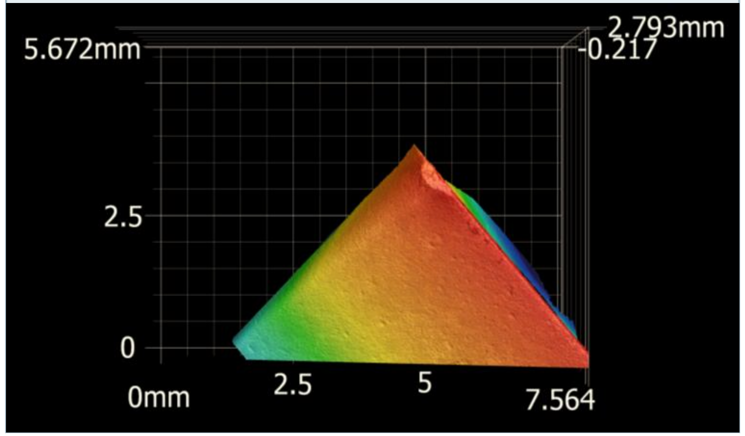
Surface roughness

- Surface measurement using Zygo Ametek NX2 WLI
- Extraction of **roughness** profiles according to DIN EN ISO 4287 and DIN EN ISO 4288:1998



Tool wear

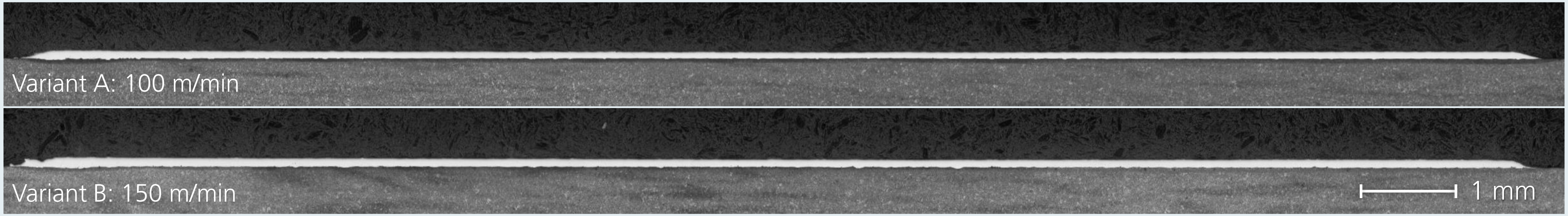
- Scan of cutting edges before and after operation using Keyence VR-5200 optical profilometer
- Qualitative comparison of cutting edges based on image data



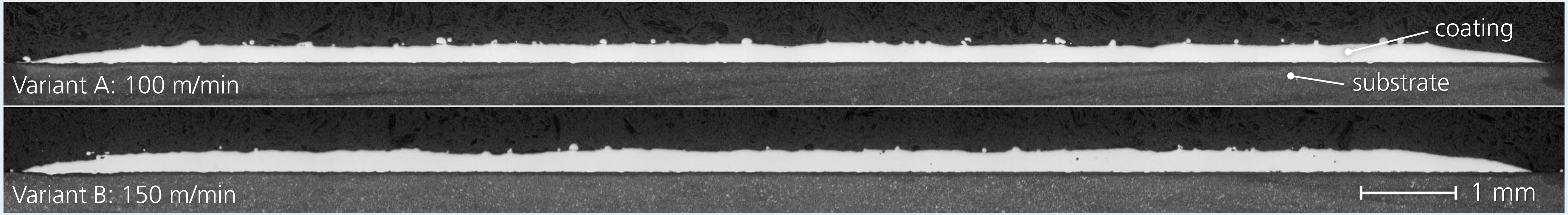
Results

Process parameter development

SMaC coatings:



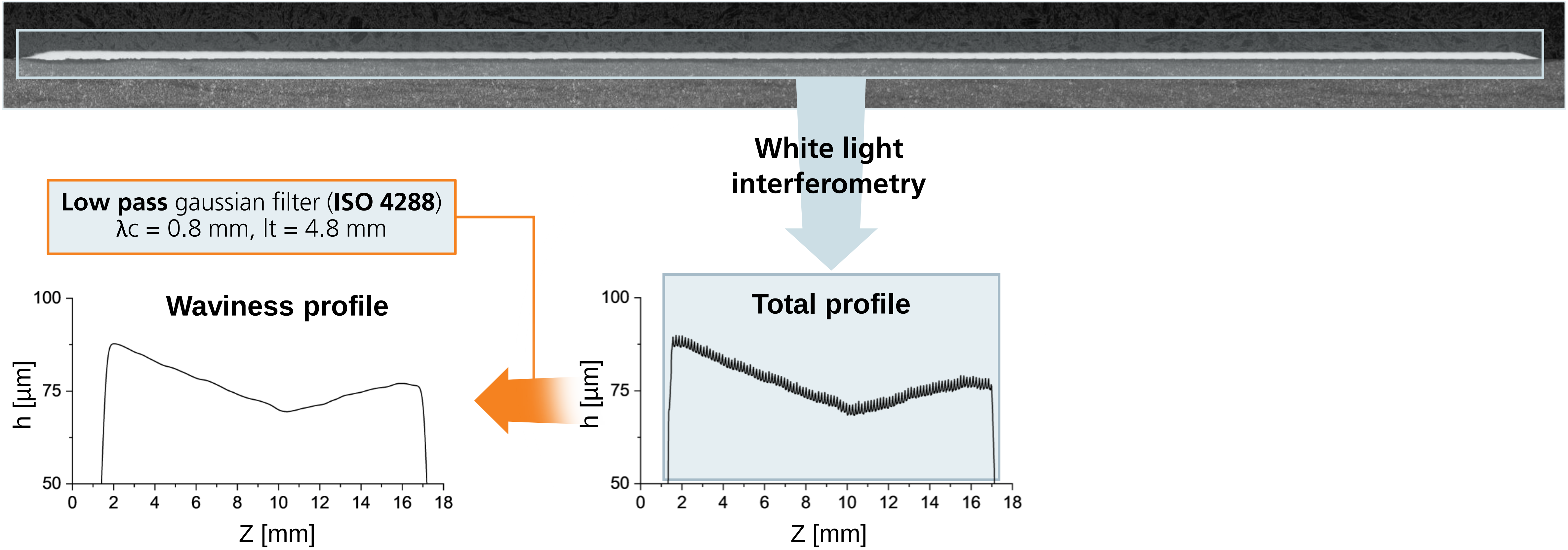
EHLA coatings:



Coating and machining feed direction →

Results

Surface profile extraction



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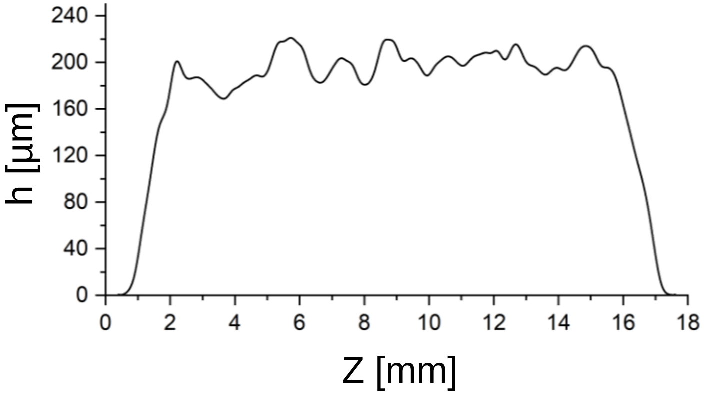
Results

Machined EHLA coating

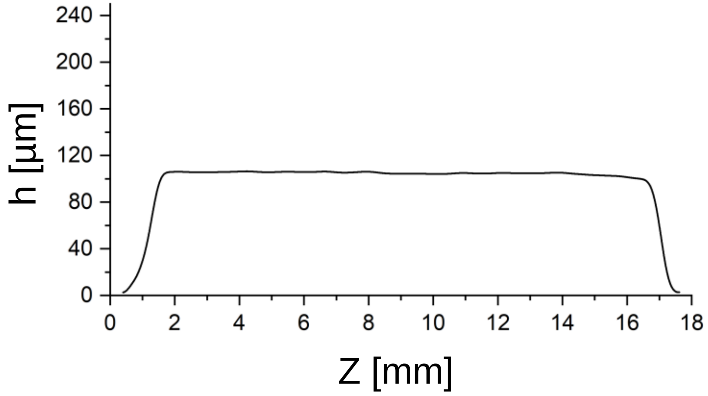
Coating and machining feed direction →

EHLA as deposited | EHLA after turning | SMaC

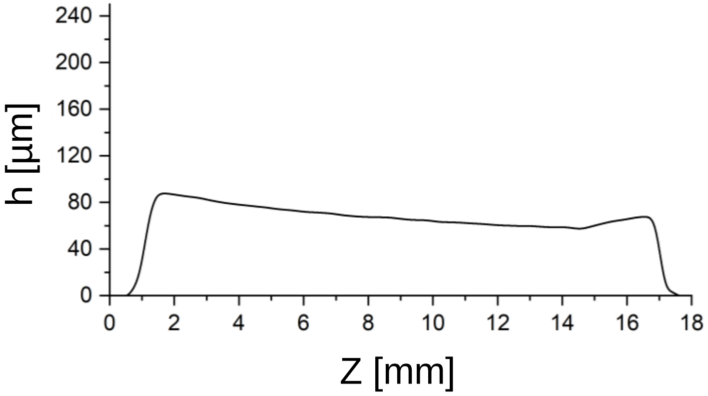
Waviness profile EHLA
as deposited



Waviness profile EHLA
after sequential turning

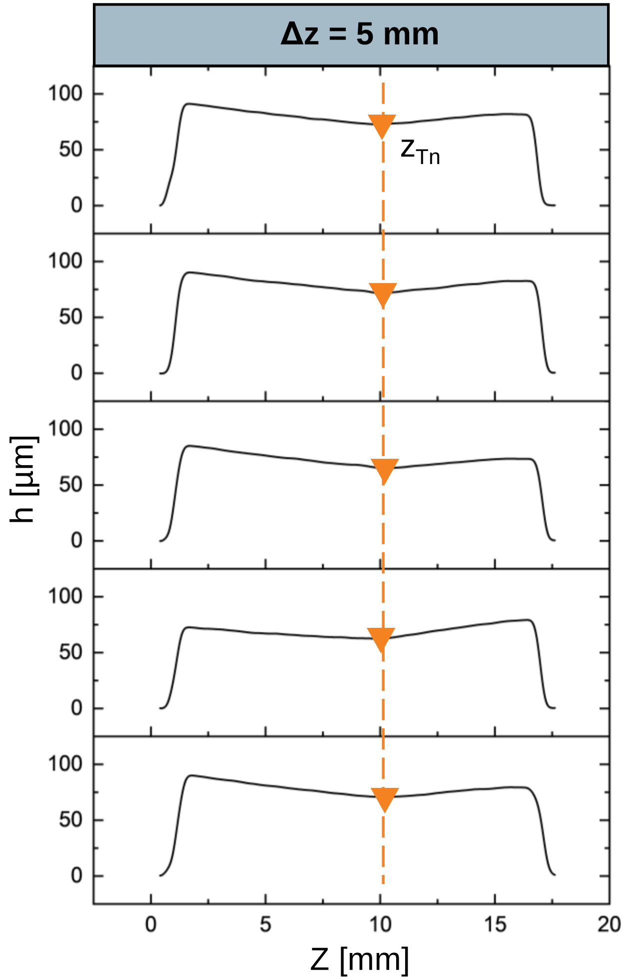


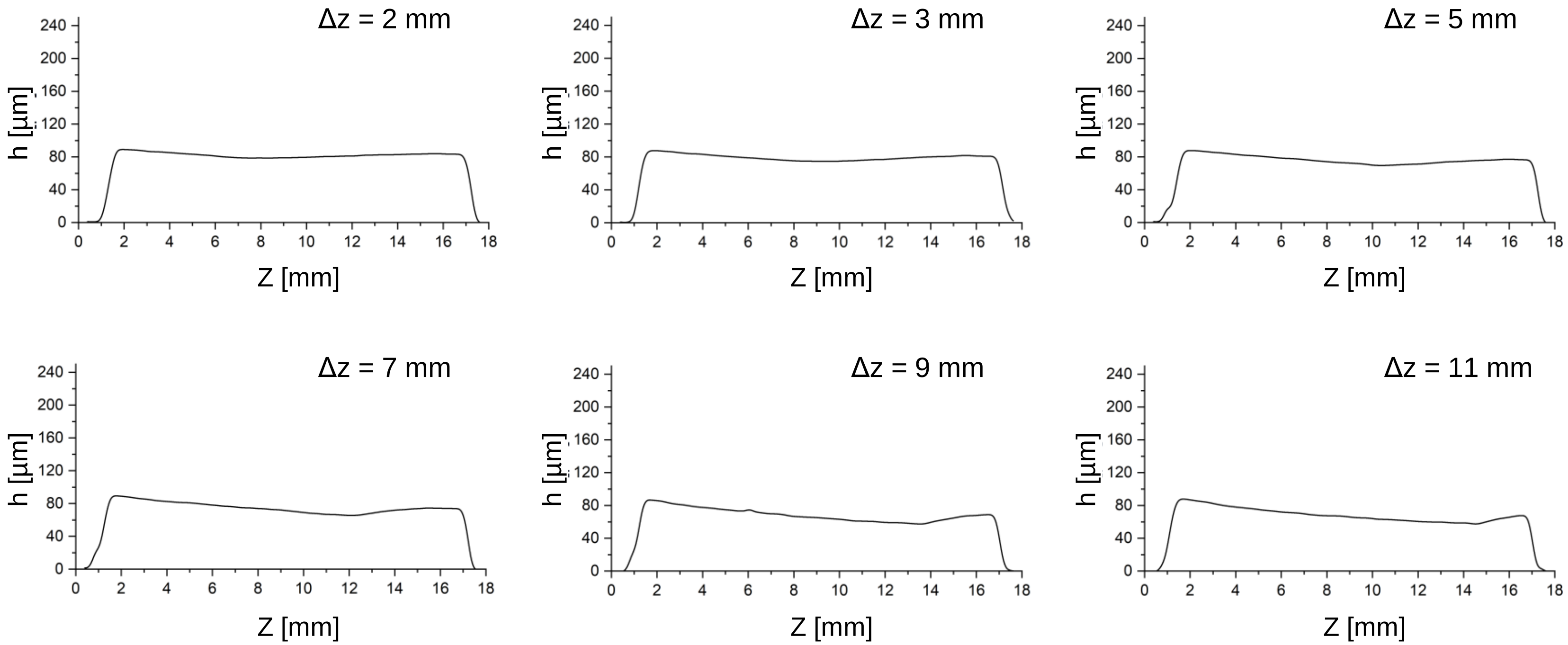
Waviness profile SMaC
with Δz = 2 mm



Results

Dimensional accuracy of SMaC coatings

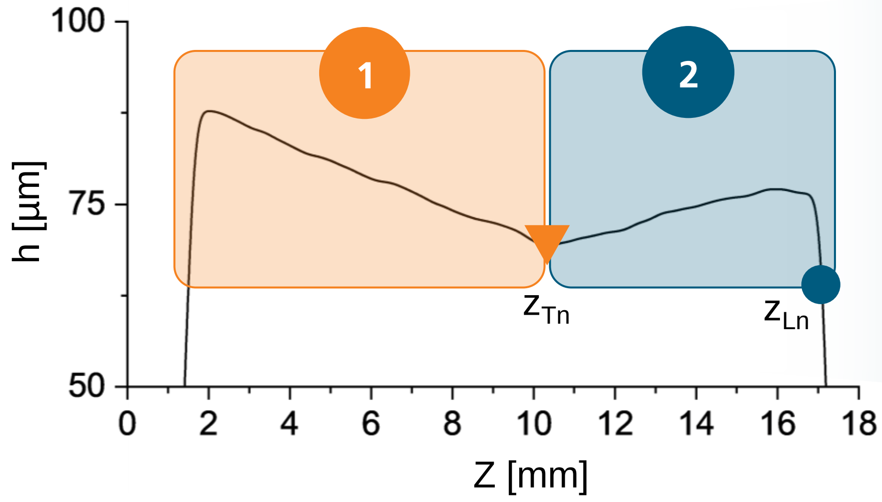




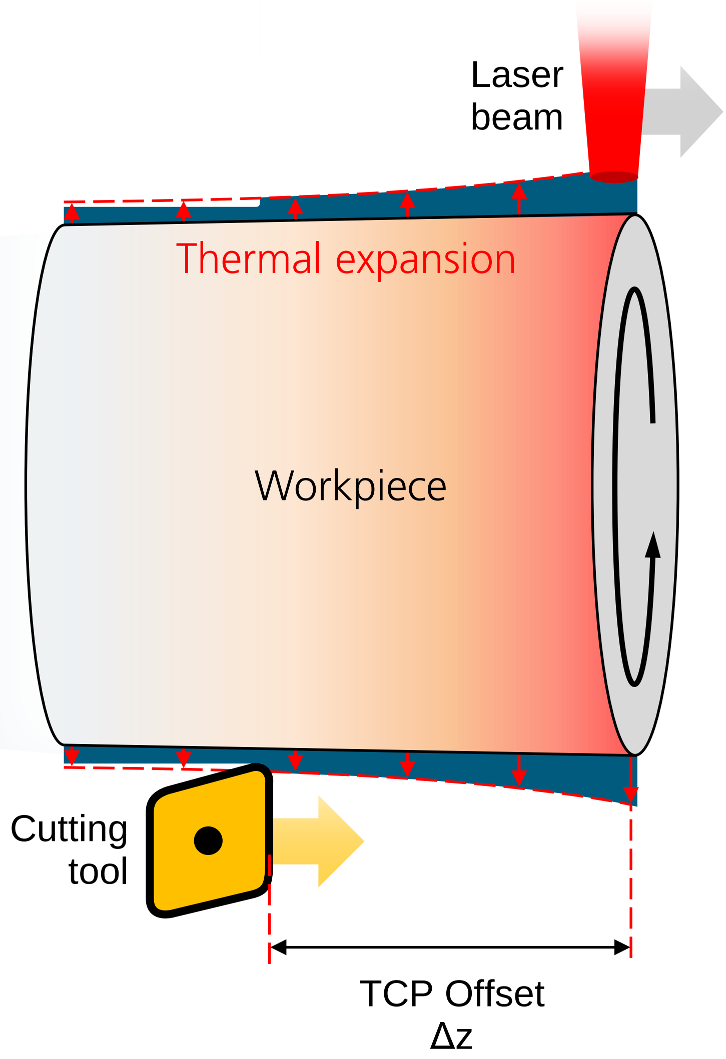
Location of local minima $\mathbf{\Delta z_{Tn}}$ in the waviness profile is consistent over the circumference of a part, but changes with different TCP offset **Δz**

Results

Dimensional accuracy of SMaC coatings



Hypothesis

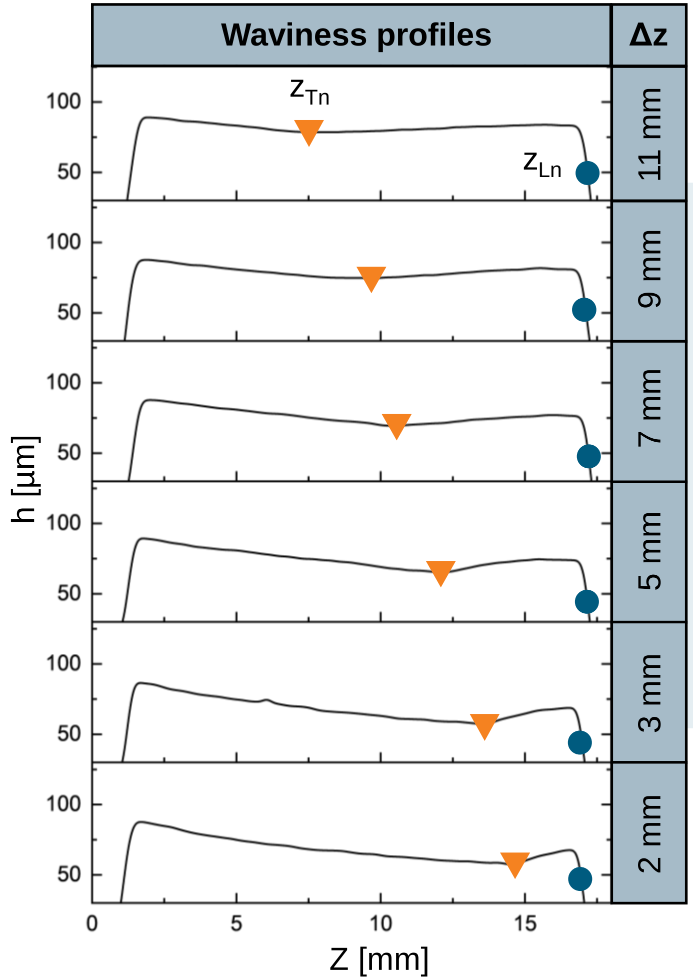


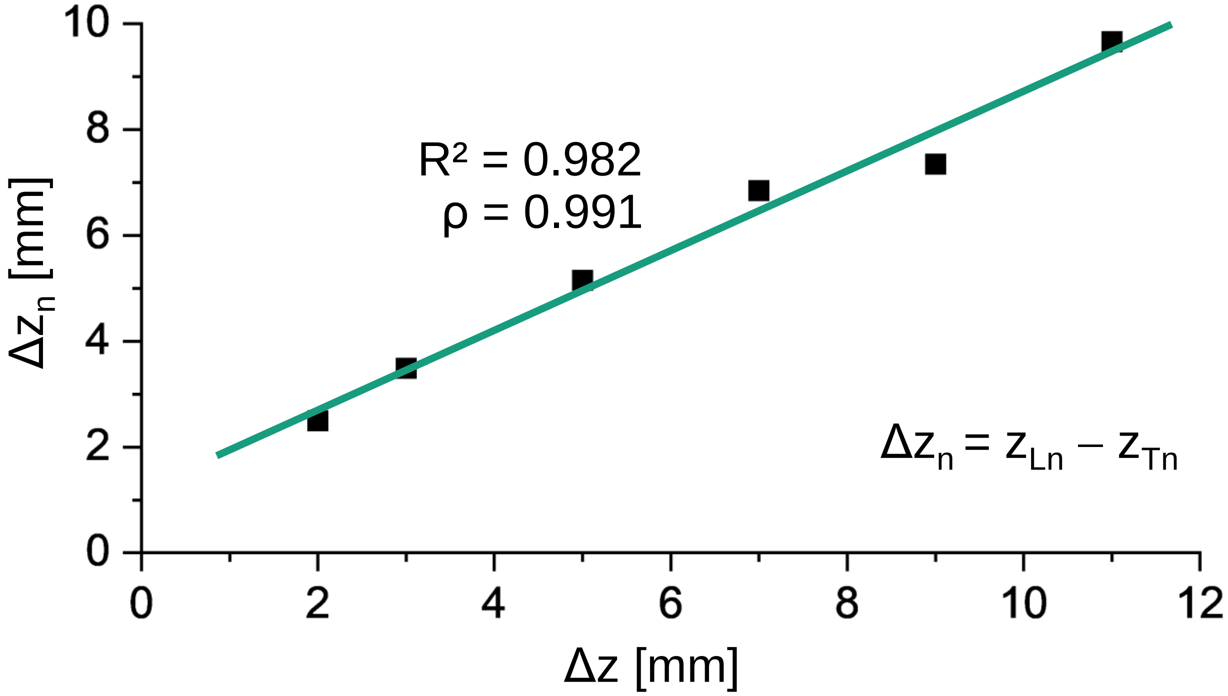
1 Continuous thermal expansion of the material when EHLA process is running
→ **cutting depth increases**

2 Rapid contraction of the material when EHLA process is finished
→ **cutting depth decreases**

Results

Dimensional accuracy of SMaC coatings

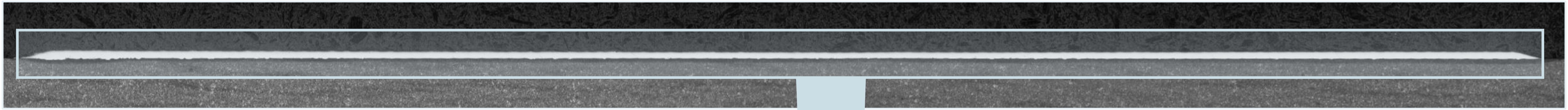




TCP offset Δz_n and the location of the local minima Δz_{Tn} in the waviness profile are strongly correlated

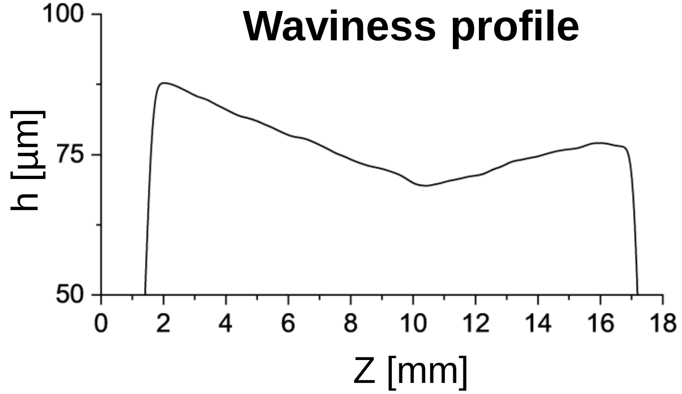
Results

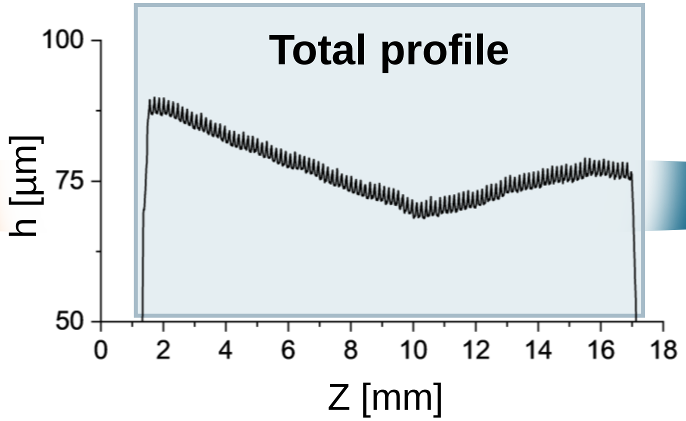
Surface profile extraction



White light interferometry

Low pass gaussian filter (**ISO 4288**)
λc = 0.8 mm, lt = 4.8 mm





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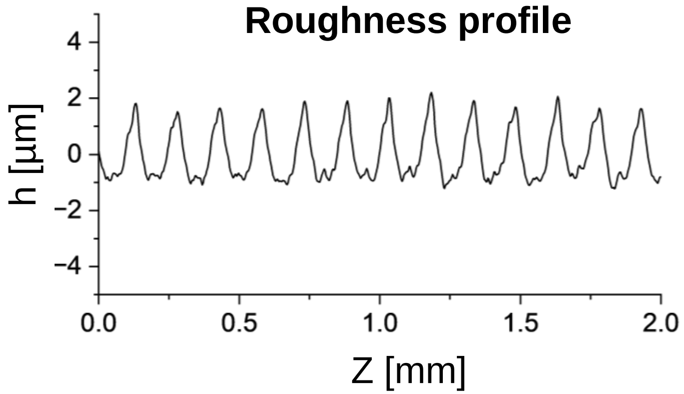
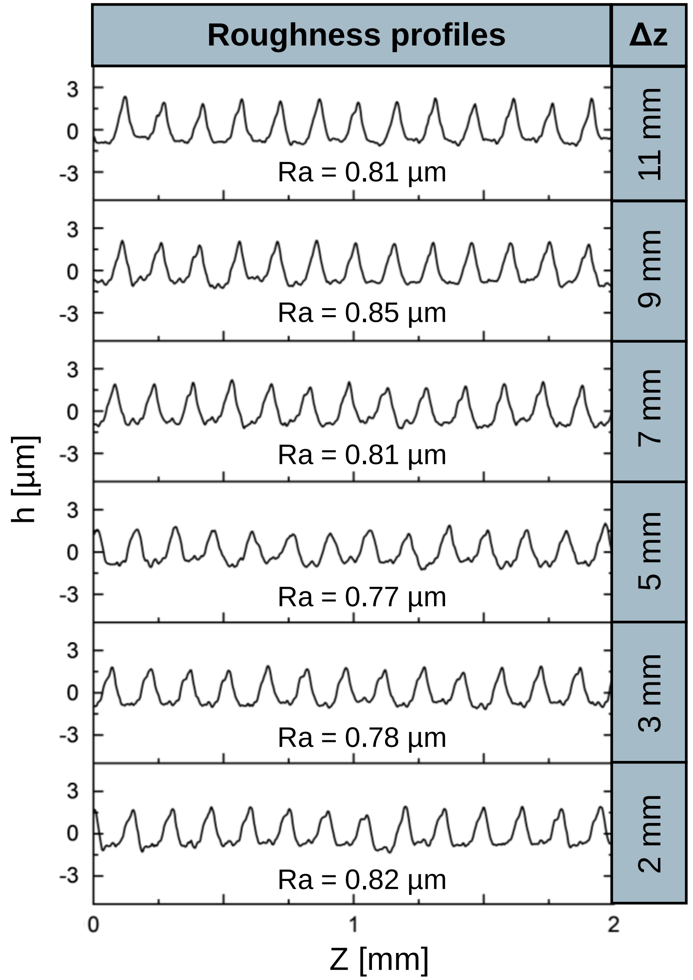
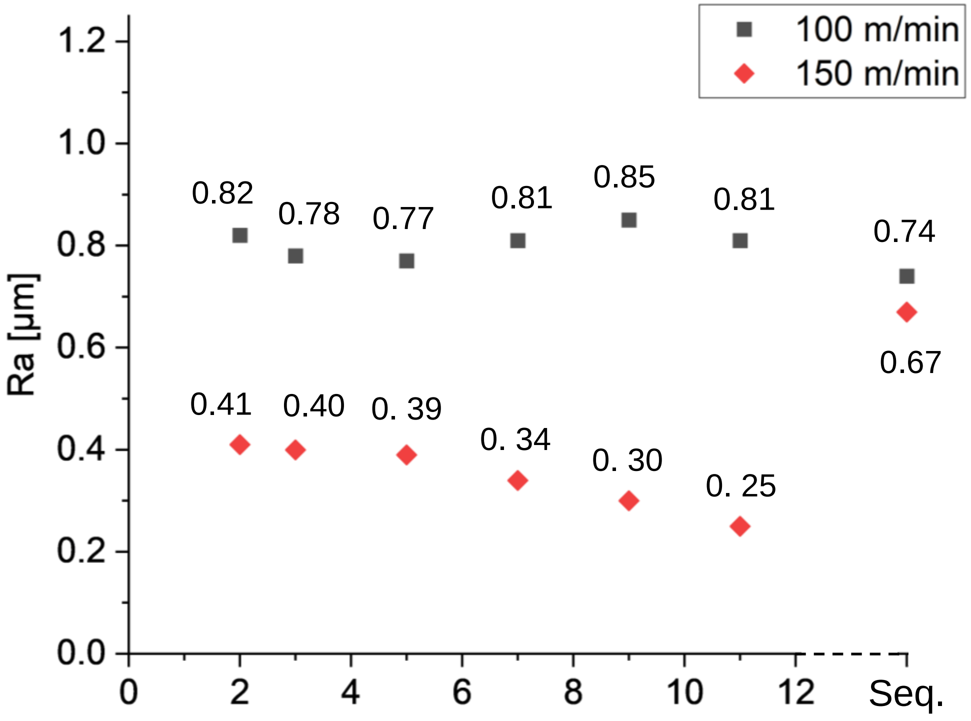


Results

Surface roughness of SMaC coatings

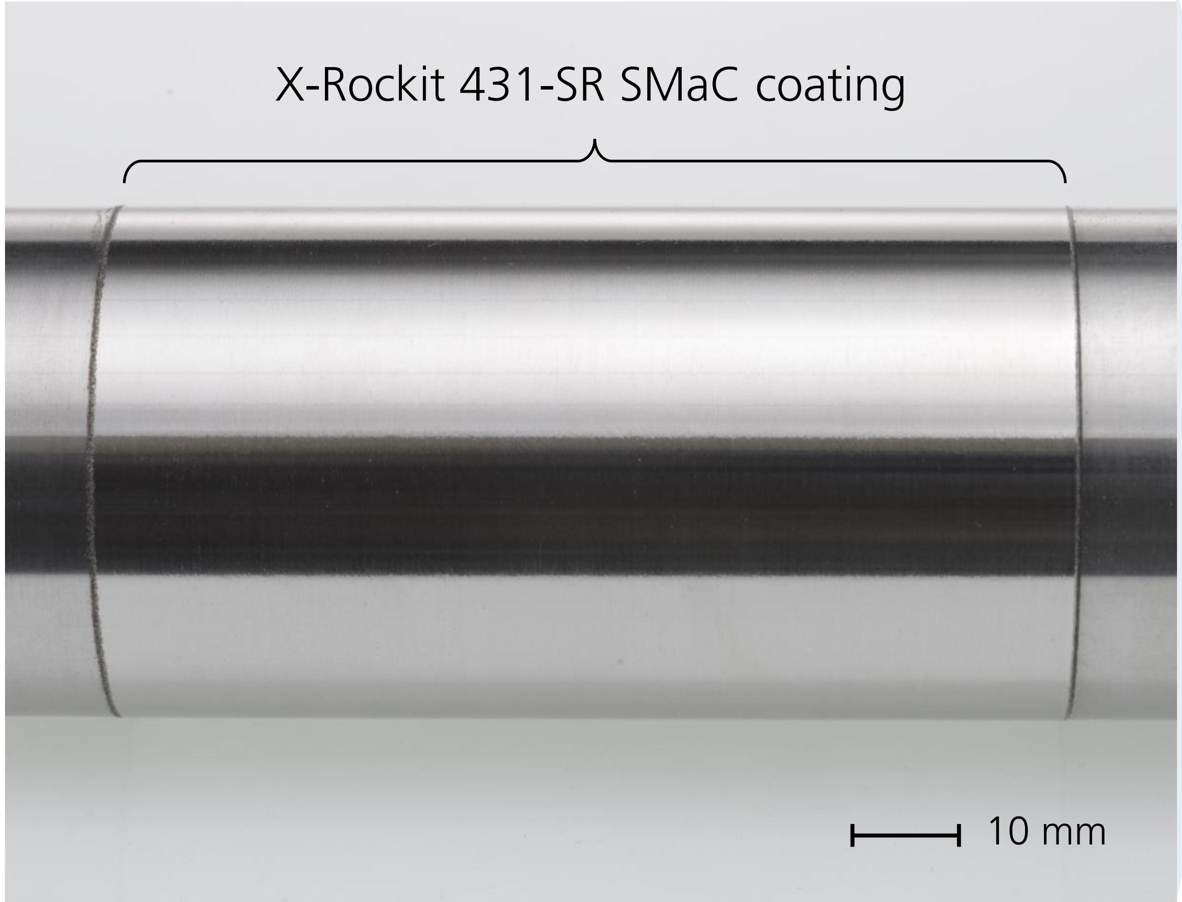


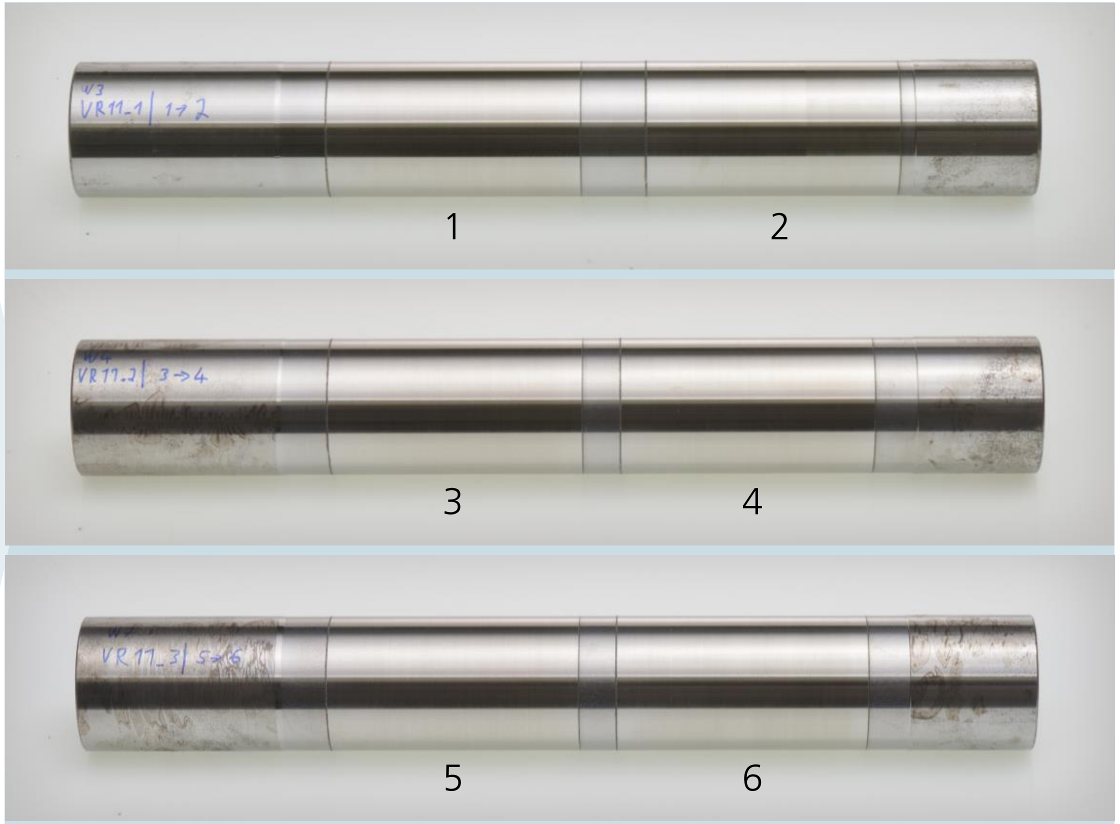


No significant difference in surface roughness between SMaC and sequential machining at 100 m/min. At 150 m/min SMaC provides a better surface finish.

Results

Investigation of tool wear

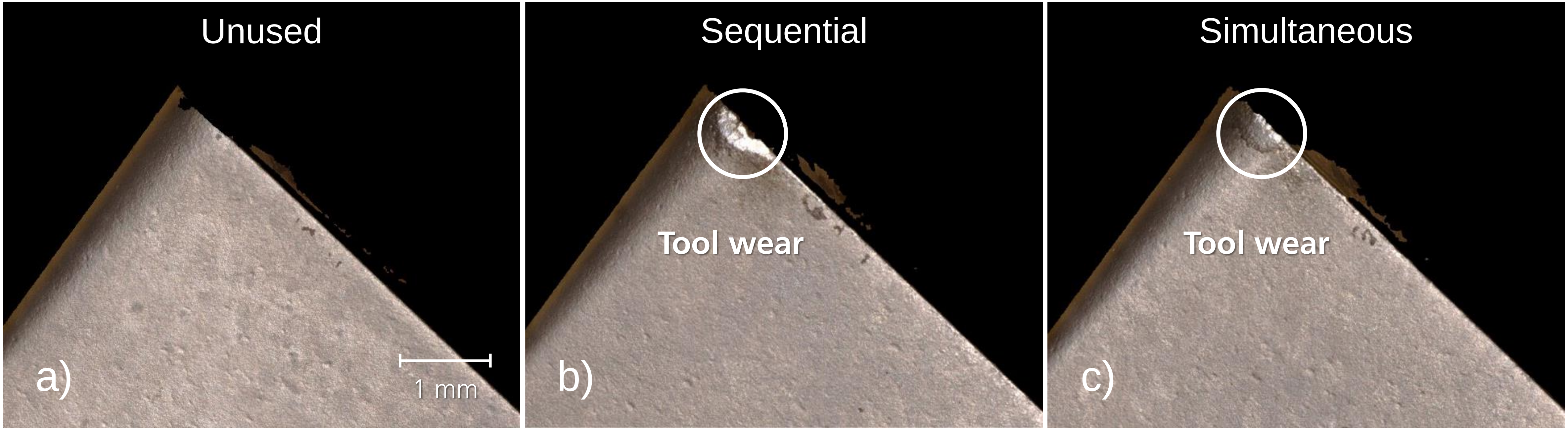




845 cm² machined surface in total

Results

Investigation of tool wear



Cutting inserts used for SMaC exhibit smaller visible signs of abrasion compared to sequential machining, indicating potential for extending the service life of the turning tool.

Conclusion and outlook

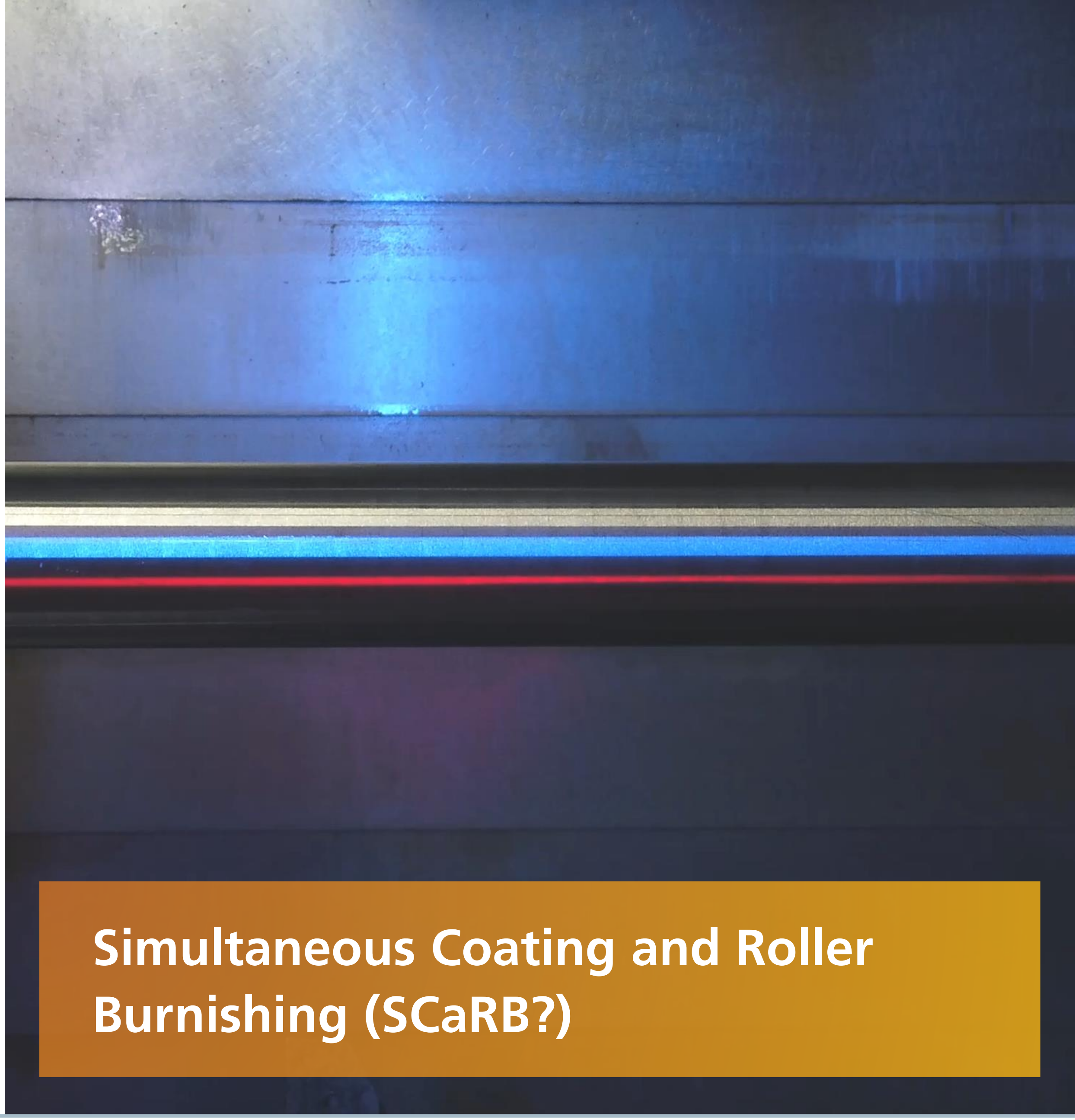
Simultaneous Machining and Coating (SMaC)

Conclusion

- Positive effect of SMaC on surface roughness observed
- Positive effect of SMaC on tool wear was observed
- Dimensional deviation is strongly correlated to the programmed TCP offset and is linked to thermal expansion of the workpiece

Outlook

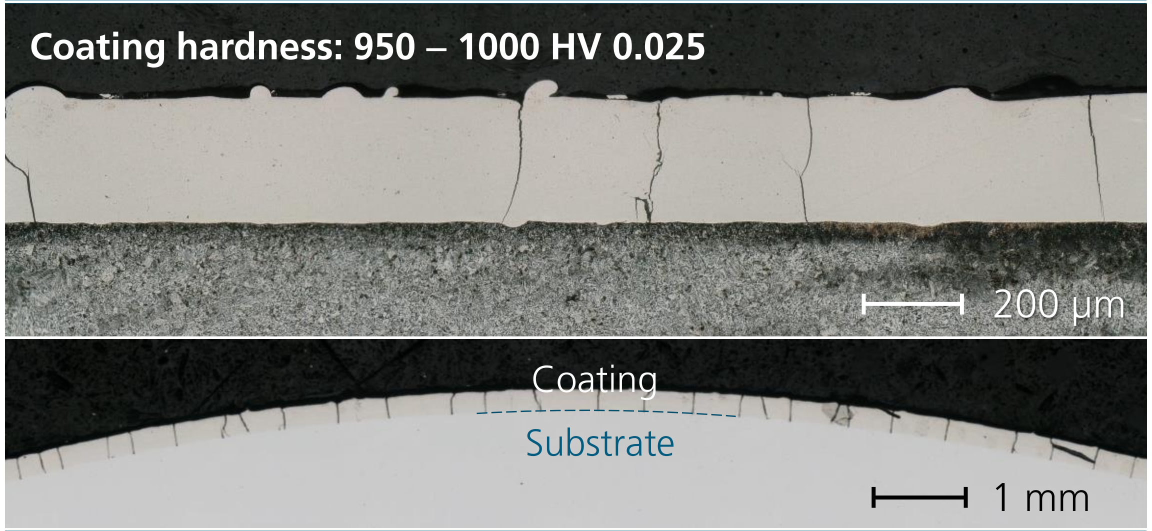
- Mitigation of dimensional deviation by active control of tool infeed
  - Closed loop system or numeric simulation
- Investigations into the effect of Δz on cutting force using piezoelectric force sensors
- Exploring *further process combinations*, such as SCaRB
- Investigation of the compressive stresses induced into the coating by the cutting tool



Outlook

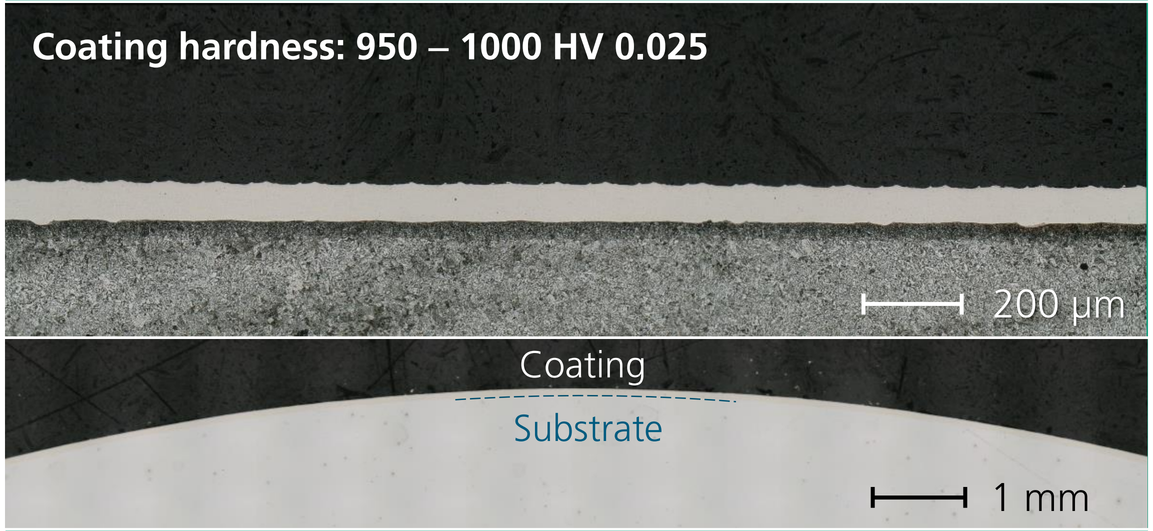
Enhanced coating and machinability of very brittle materials, such as NiCrBSi

EHLA



EHLA coatings exhibit **cold cracks** induced by high thermal stress. Post-machining by **turning is not feasible** due to high hardness & brittleness of the material.

SMaC



With SMaC, **crack-free coatings** can be deposited due to compressive stresses induced by the tool. Simultaneous **turning is possible** despite high hardness & brittleness.

CONTACT

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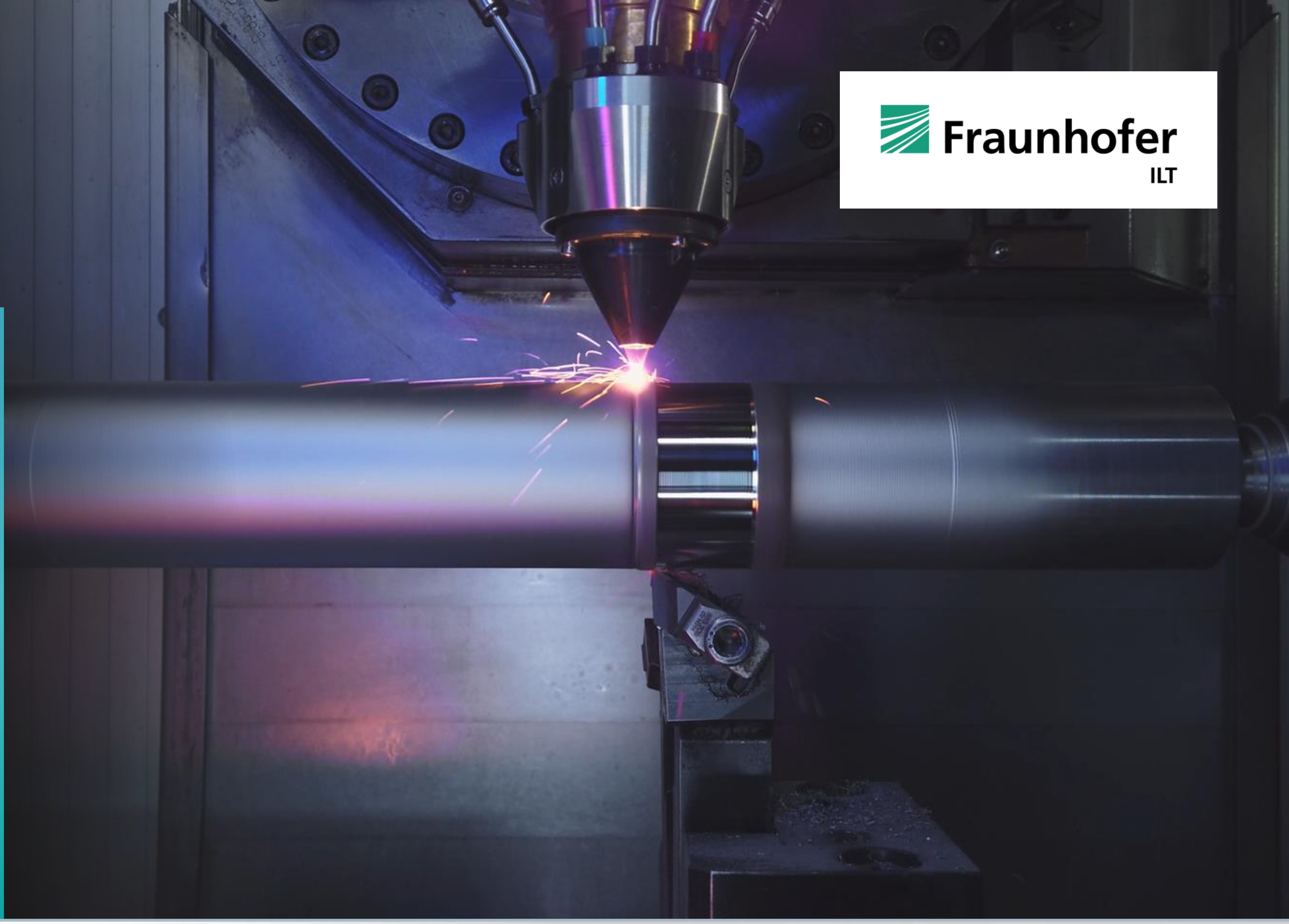

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