Tailoring of workpiece geometry and coating microstructure in laser cladding processes

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Emporia, Aachen, May 16th - 17th, 2023

Outline

- Brief company introduction
- Motivation for laser cladding of brake disks
- Process characteristics
- Cladding microstructure and properties
  - Phase composition, crystallite size and orientation
  - Microhardness
  - Crack formation and propagation
- Influence of feedstock properties
  - Stainless steel matrix
  - Carbide reinforcement
- Influence of particle speed and particle density distribution
- Influence of welding strategy

GTV company

founded in 1983

> 30 Mio. € turnover

2 locations
D-Luckenbach
CN-Beijing

94 employees
10 in RnD

Owners and CEOs:
Dr.-Ing. Klaus Nassenstein
Dr.-Ing. Konstantin von Niessen

Motivation for coating of brake disks

- Aesthetics
- Corrosion resistant friction ring surface
- Stable friction coefficient despite mostly regenerative braking
- Reduced particle emission
- Non-hazardous wear debris

Motivation for laser cladding of brake disks

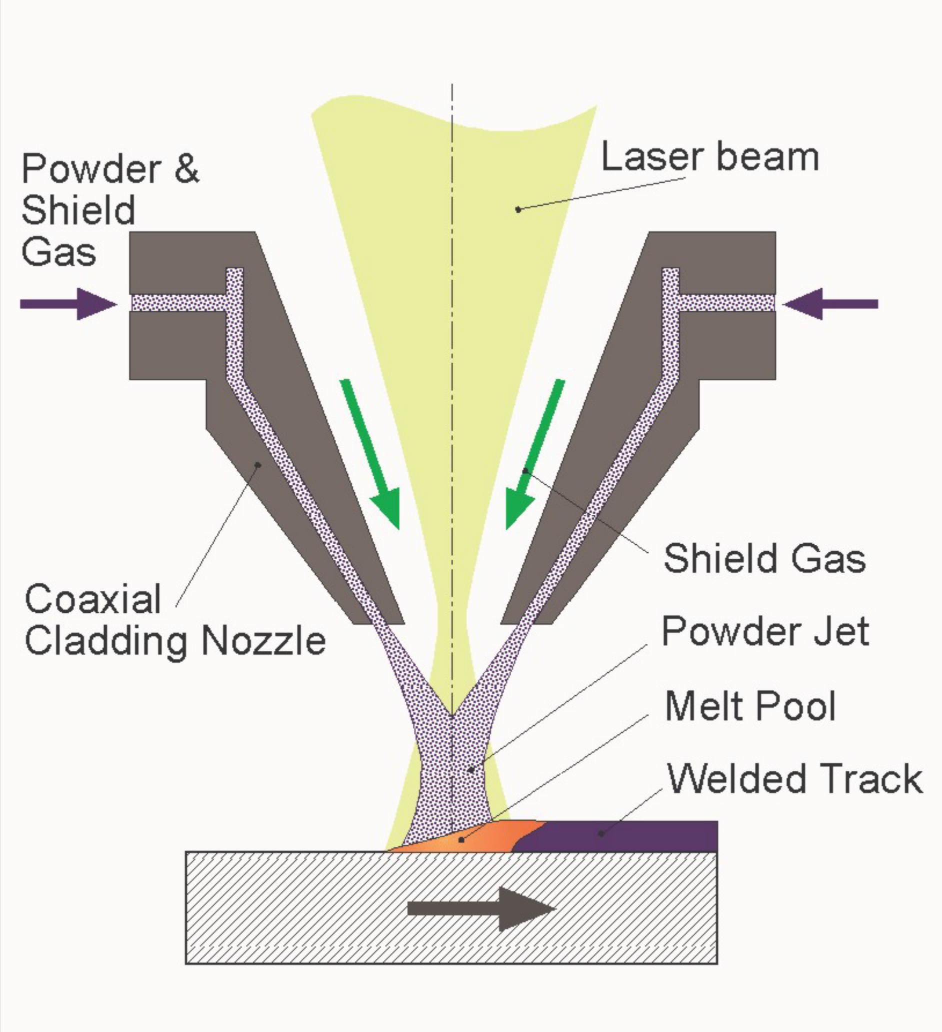
- Metallurgical bonding between substrate and coating
- Gas tight claddings
- Low heat input
- Low dilution with base material
- Limited distortion
- High deposition efficiency
- High deposition rate possible
- High reproducibility

Process characteristics

- 6-stream powder nozzle

  tailored particle density distribution and

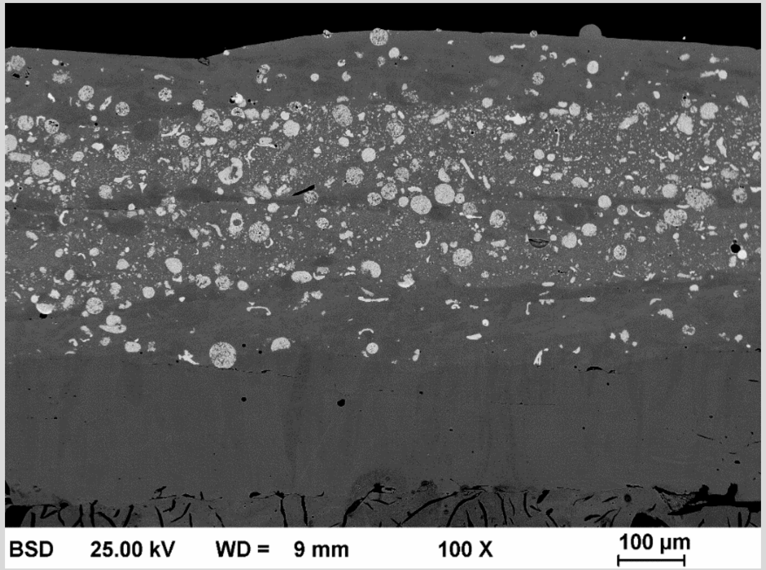
  tailored speed of powder components
- Up to 22 kW laser power, 300 g/min powder feed rate at 90% DE, 400 m/min cladding speed, overlap > 90%
- 80 - 500 µm layer thickness
- Stainless steels + NbC / TiC / W_2C/WC

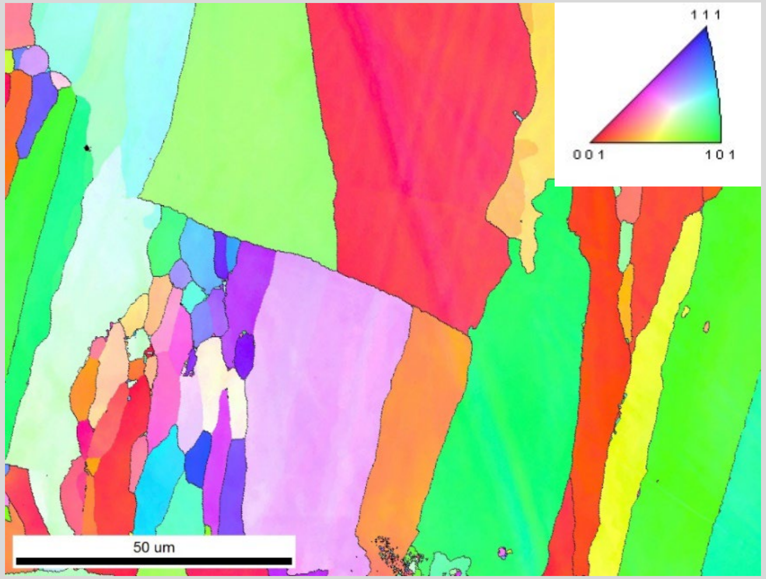


Laser cladding process

Cladding properties - microstructure

- Directional solidification
- Partially epitaxial crystal growth through bead and layer boundaries
- Multi-layer claddings with graded carbide content possible, advantageous stress state
- Pre-heating permits increased carbide contents without crack formation

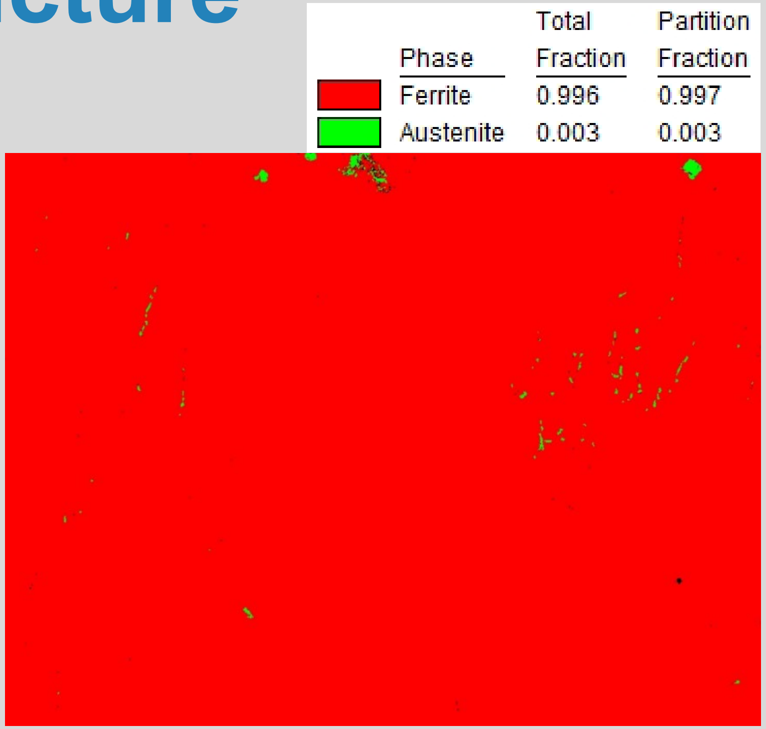


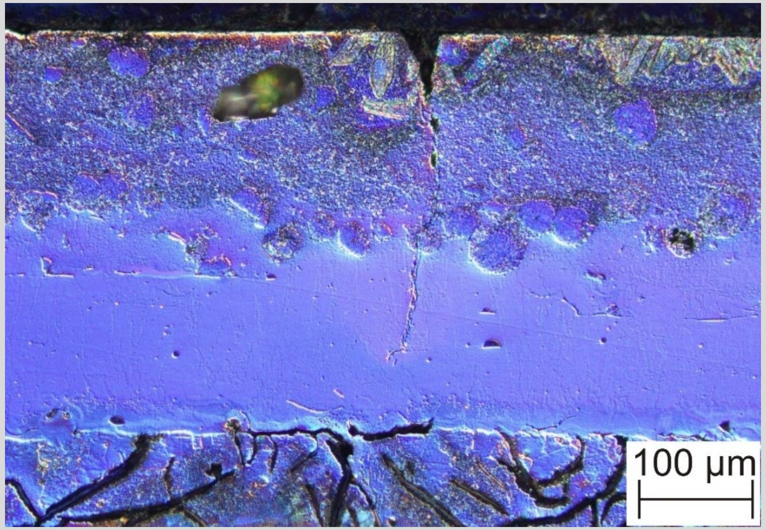


Cladding properties - microstructure

- Non-equilibrium phase composition

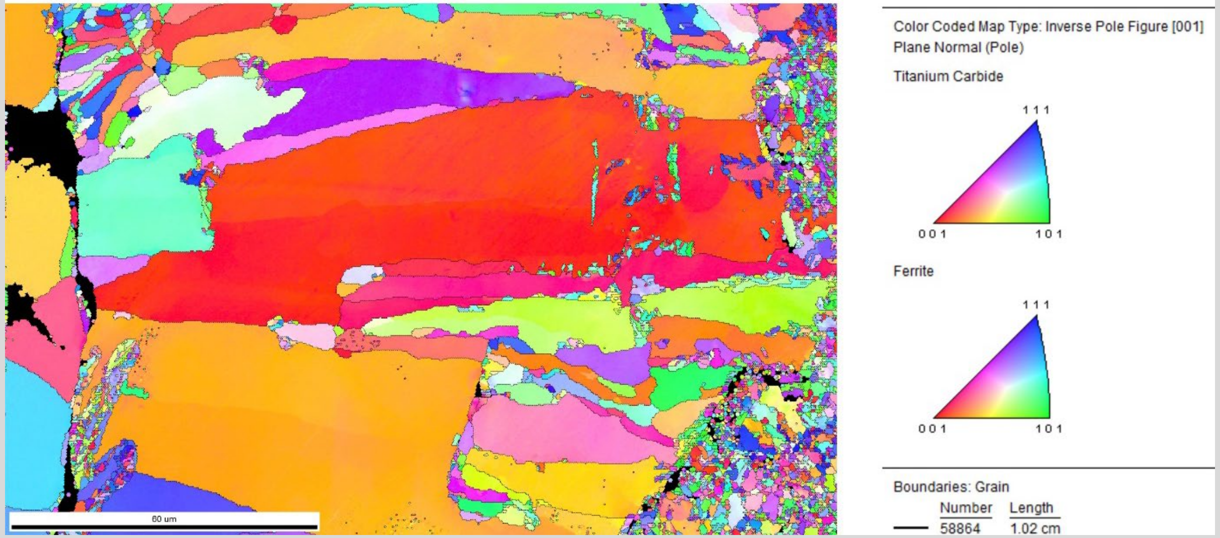
  AISI318LN solidifies basically 100% ferritic
- Carbide reinforcement results in reduced orientation preference and smaller grain size
- Thermal crack tests cause crack initiation at surface, cracking starts in substrate before cracks propagate through base layer without carbide reinforcement

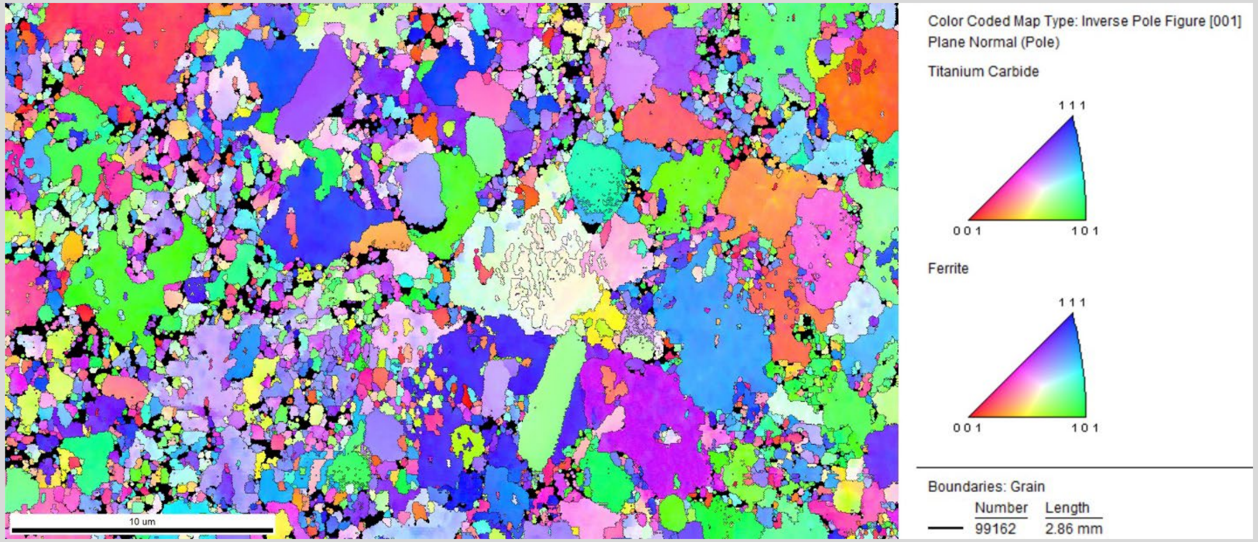




Cladding properties - microstructure

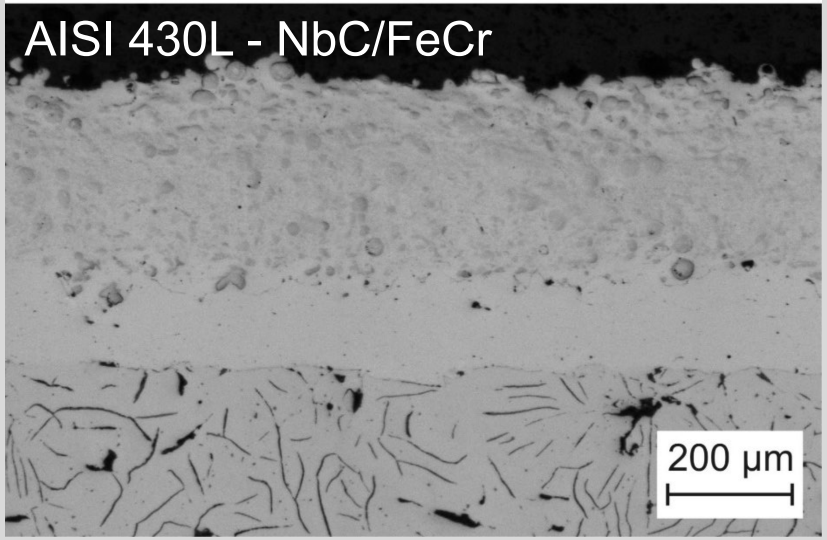
- Tribologically induced heat treatment during thermal crack testing causes grain coarsening only in grey cast iron substrates and stainless steel layers without carbide reinforcement

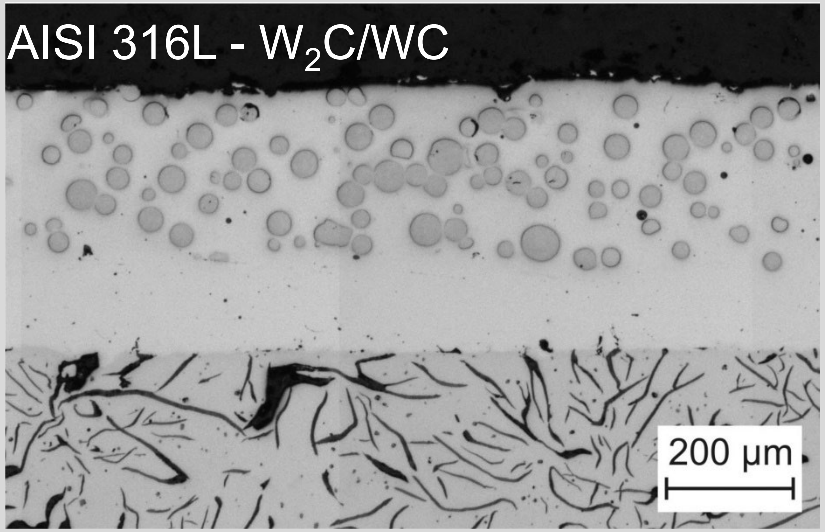




Cladding properties - microhardness

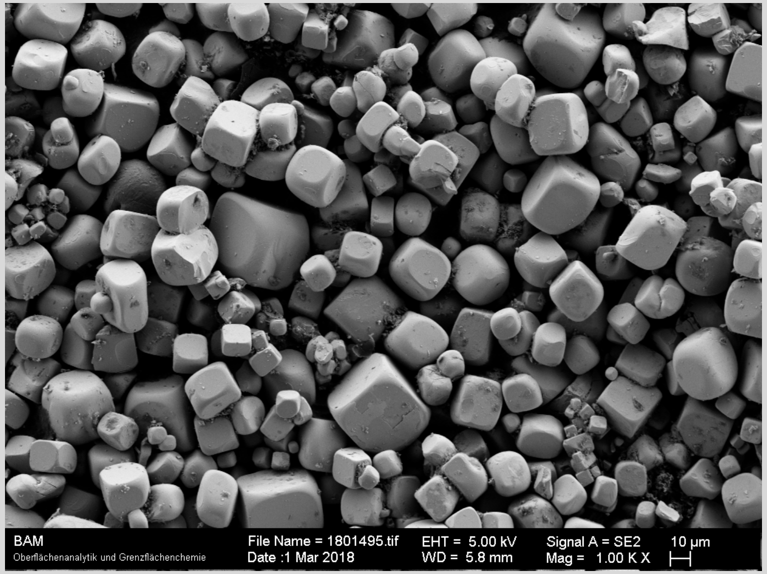
- 30 vol.-% NbC and TiC reinforced stainless steel layers show average microhardness of 450-700 HV0.3 (std. dev. < 100 HV0.3)
- 30 vol.-% W_2C/WC reinforced stainless steel layers show individual microhardness values of 400-2,500 HV0.3 with average of 900-1,400 HV0.3

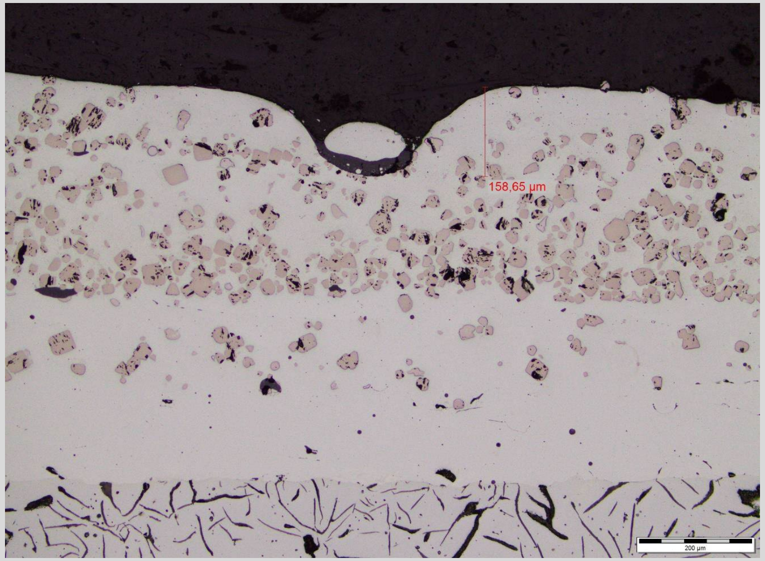




Cladding feedstock development

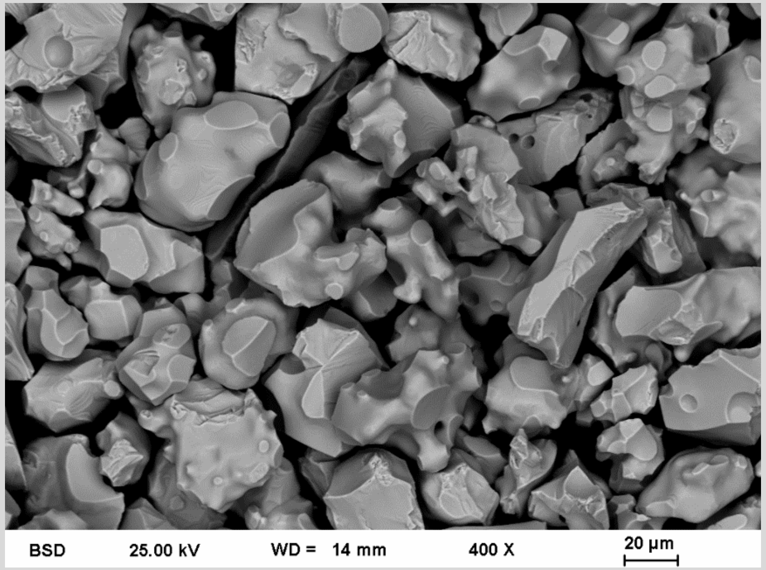
- NbC cubes, leached
- Avg. diameter ~ 30 µm
- Good feed rate stability
- Good wetting by stainless steel matrices
- Small specific surface area, low dilution
- Crater formation due to Al_2O_3 contamination arising from production process
- Limited availability

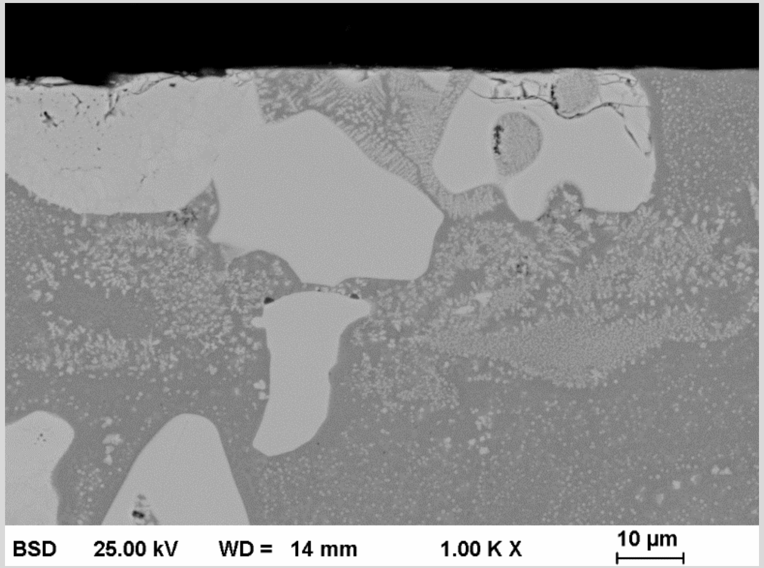




Cladding feedstock development

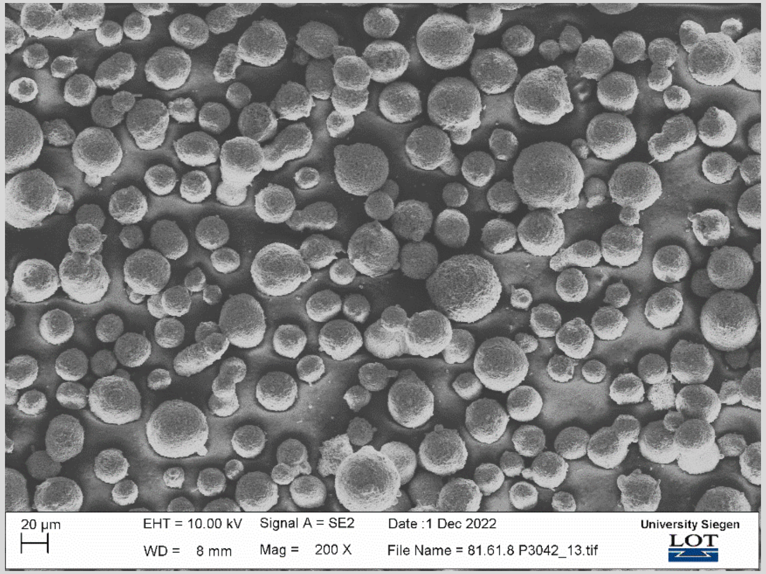
- NbC (/ TiC), sintered & crushed
- Avg. diameter ~ 40 µm
- Limited feed rate stability
- Good wetting by stainless steel matrices
- Large specific surface area, strong dilution
- Dendritic carbide precipitates
- Transfer of cracks caused by crushing procedure into claddings

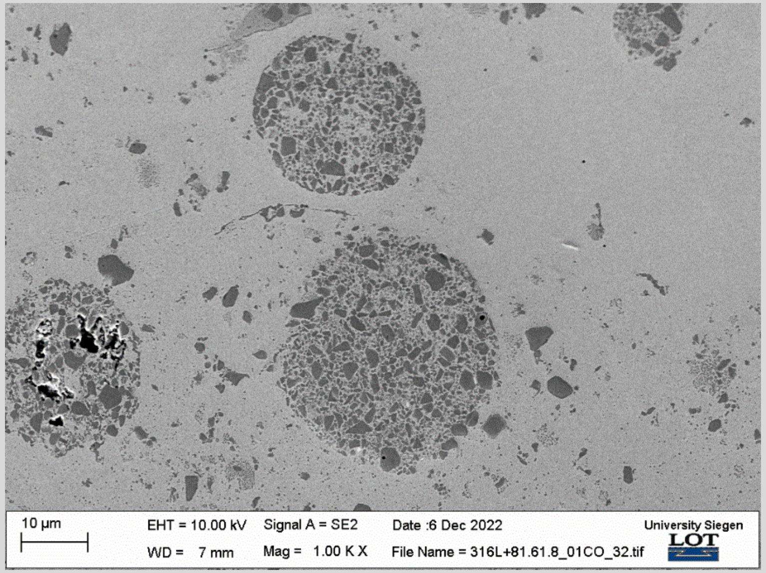




Cladding feedstock development

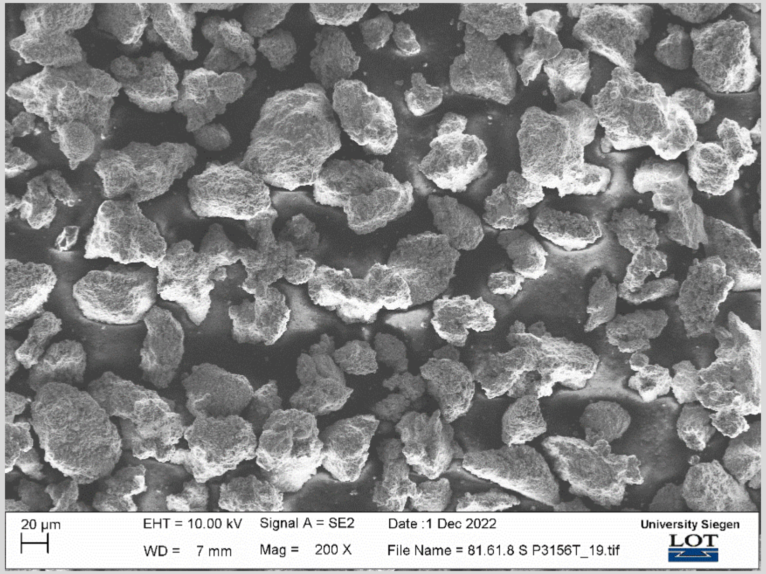
- TiC/FeCr (/ NbC/FeCr), aggl. & sintered
- Avg. diameter ~ 25 µm, FSSS 1 µm
- Excellent feed rate stability
- Good wetting by stainless steel matrices
- Small specific surface area, low dilution
- Limited cohesion within large composite particles that are not penetrated by stainless steel melt

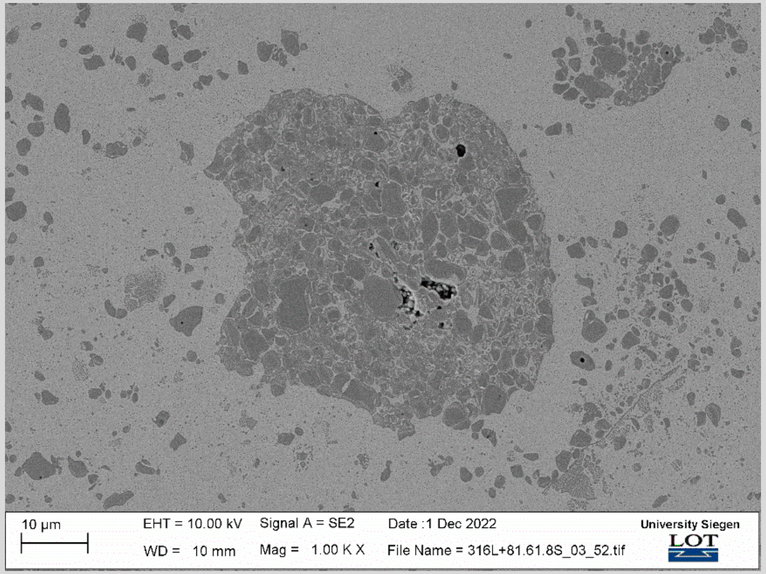




Cladding feedstock development

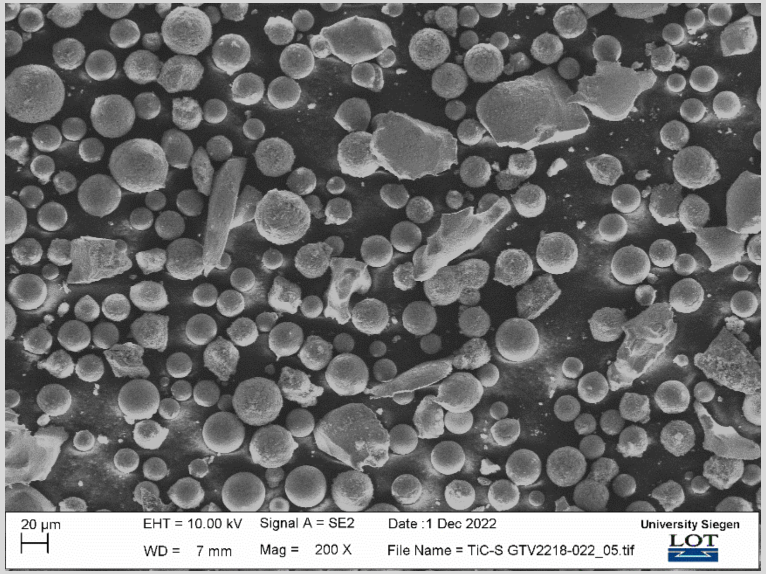
- TiC/FeCr, sintered & crushed
- Avg. diameter ~ 40 µm, FSSS 1 µm
- Good feed rate stability
- Good wetting by stainless steel matrices
- Large specific surface area, low dilution
- High cohesion even within large composite particles that are not penetrated by stainless steel melt

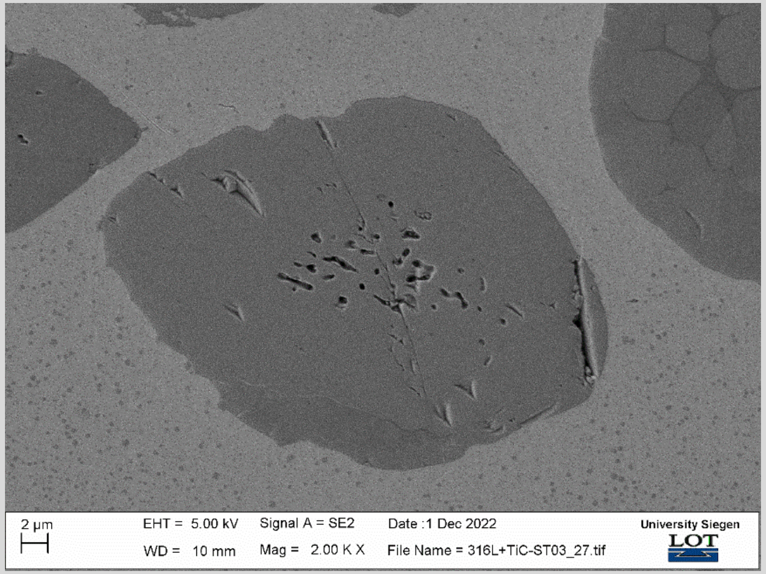




Cladding feedstock development

- TiC (/ W_2C/WC), plasma spheroidized
- Avg. diameter ~ 40 µm
- Excellent feed rate stability
- Good wetting by stainless steel matrices
- Small specific surface area, low dilution
- Actually still limited availability



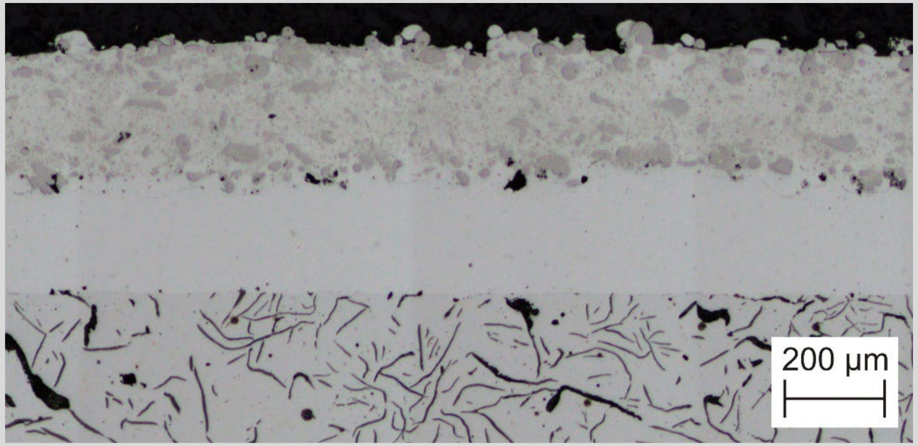


Cladding feedstock development

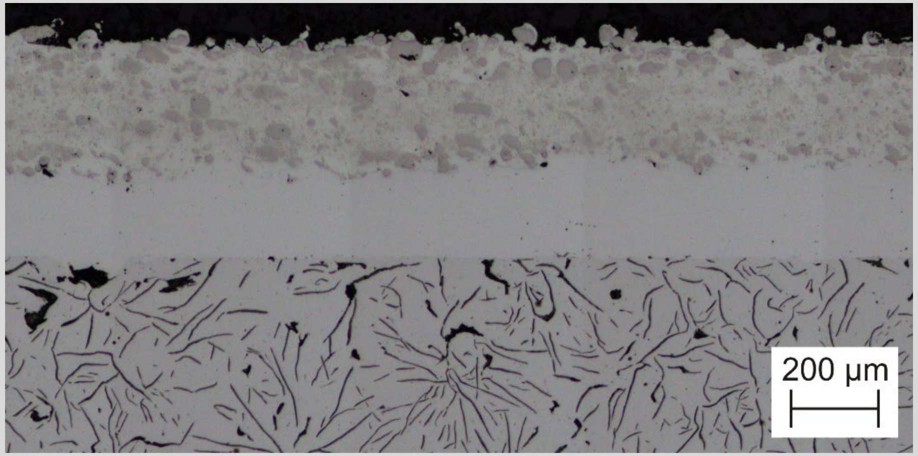
production route	feed stability	dilution in matrix	carbide crack resistance	cladding strength	availability
leached	+	+	+	+	--
sintered and crushed	-	-	-	0	+(+)
agglomerated and sintered composite	++	+	++	0	+(+)
sintered and crushed composite	+	+	++	+	+(+)
plasma spheroidized	++	+	+	+	-

Particle density distribution influence

- Control of local particle density permits influence on local laser interaction with substrate / previous cladding layer surface



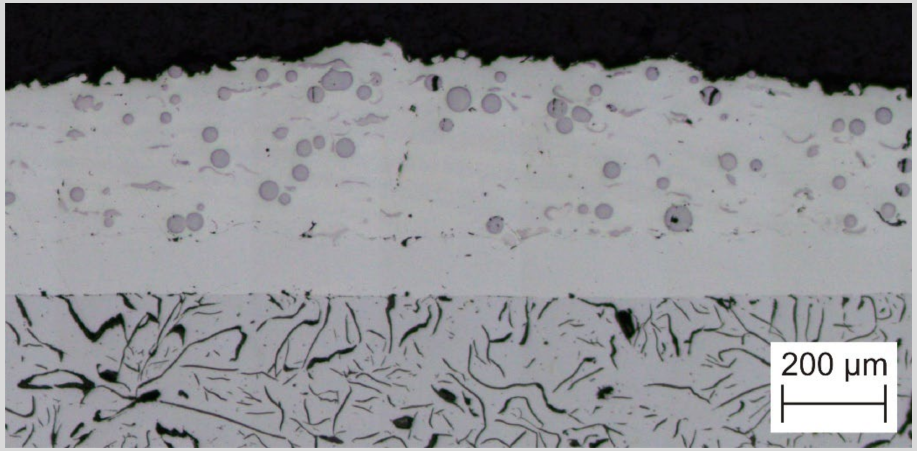
28/29/27/27 g/min stainless steel
17/17 g/min TiC/FeCr 70/30



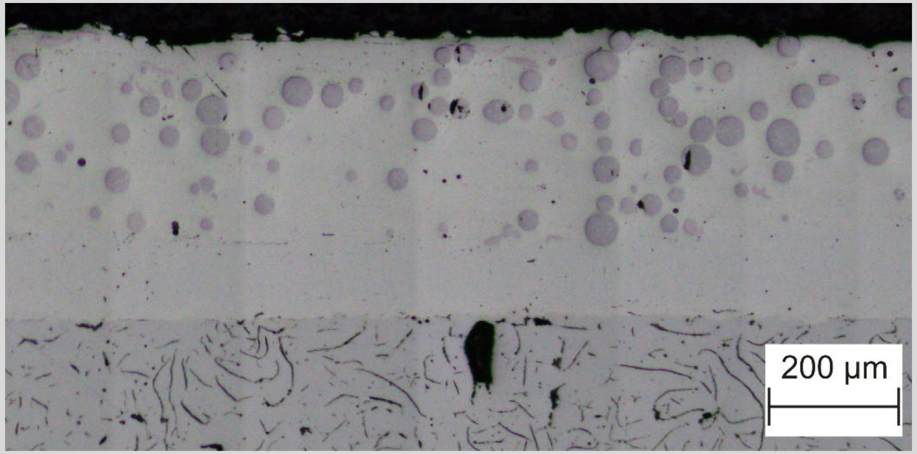
32/32/24/23 g/min stainless steel
21/13 g/min TiC/FeCr 70/30

Particle speed influence

- Heat transfer to carbide particles on their way into the melt pool can be tailored by particle speed / dwell time inside the laser beam
- Flattening degree and degree of carbide dissolution in stainless steel melts depends on heat transfer to inflight particles



Carrier gas Ar, FTC_s 2x 4 l/min



Carrier gas Ar, FTC_s 2x 6 l/min

Influence of welding strategy

- Distortion depends on brake disk design;

  deposition of 500 µm thick cladding on one side can cause more than 800 µm distortion
- Small and composite brake disks advantageous
- Welding strategy permits minimizing distortion after cladding of both sides
- Distortion increases with total heat transfer

welding strategy	avg. distortion towards CO
CI (io, oi, io) CO (io, oi, io)	100,0%
CI (oi, io, oi) CO (oi, io, oi)	95,8%
CO (oi, io, oi) CI (oi, io, oi)	32,8%
CO (io, oi, io) CI (io, oi, io)	27,8%
CO (oi, io, oi) CI (io, oi, io)	17,0%
CO (oi, io, oi) CI (oi, oi, io)	9,3%
CO (oi, io, oi) CI (io, io, io)	-12,8%

Influence of residual stresses before cladding

- Distortion after cladding depends on residual stress state before cladding process
- Cladding of disks from two raw disk batches in random order can result in distinguishable distortion state; e.g.:

  Batch 1: range 22 - 46 µm

  Batch 2: range 47 - 57 µm
- Stress relief annealing prior to pre-machining necessary / cost advantageous?

Influence of thermal history

- Surface appearance after AK Master dyno test

cladding of CI, cooling to RT, cladding of CO; 430L + 430L / TiC

CI

CO

Influence of thermal history

- Surface appearance after AK Master dyno test

cladding of CI, cladding of CO without interim cooling; 430L + 430L / TiC

Influence of thermal history

- Surface appearance after AK Master dyno test

cladding of CO, cladding of CI without interim cooling; 430L + 430L / TiC

Summary

- High productivity laser cladding processes available for coating of grey cast iron brake rotors
- Ongoing development of optimized feedstock for optimal tribological performance and corrosion protective function of claddings
- Comprehensive optimization of process conditions needs to include powder particle density distribution, speed of feedstock components and welding strategy

Thank you very much for your attention!

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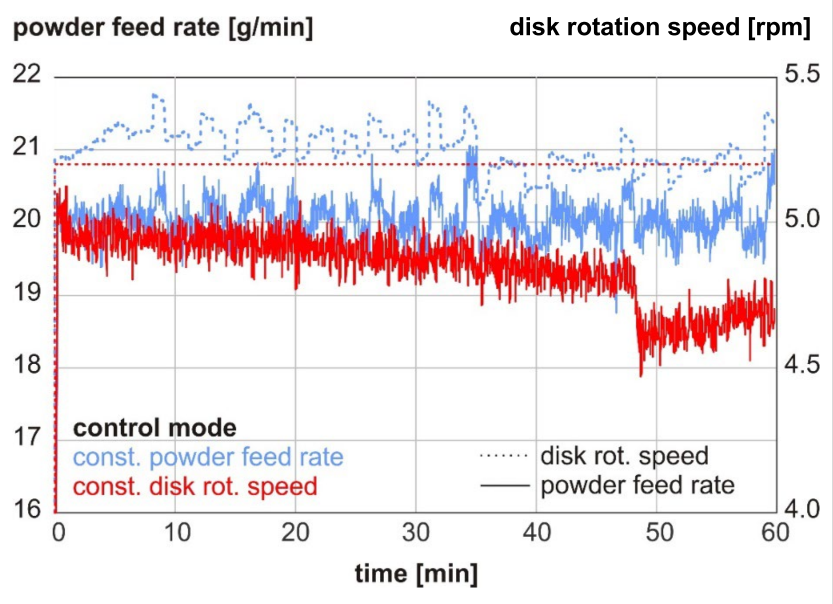
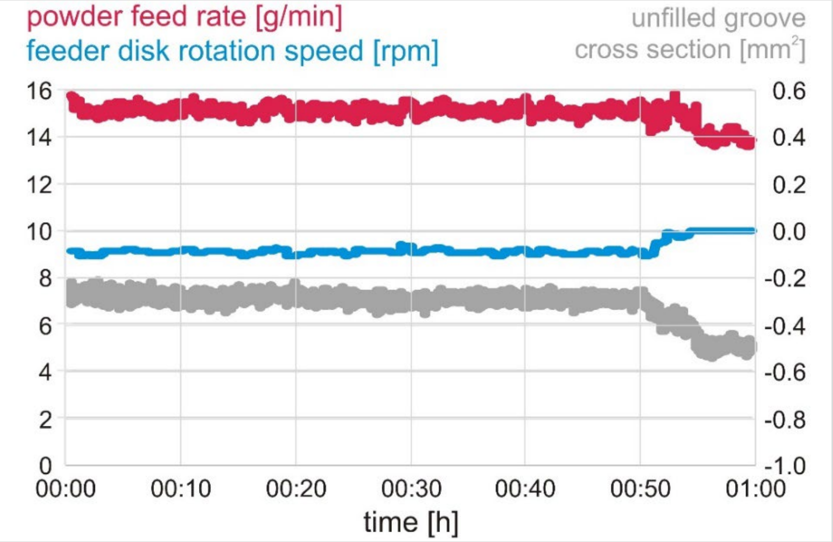
Process monitoring and control tools

- Disk type feeders permit fast change of powder feed rates for individual layers
- Scale powder feeders permit detection and compensation of abrupt and gradual change of powder feed rate
- Monitoring of disk groove filling level based on laser triangulation possible





Process monitoring and control tools

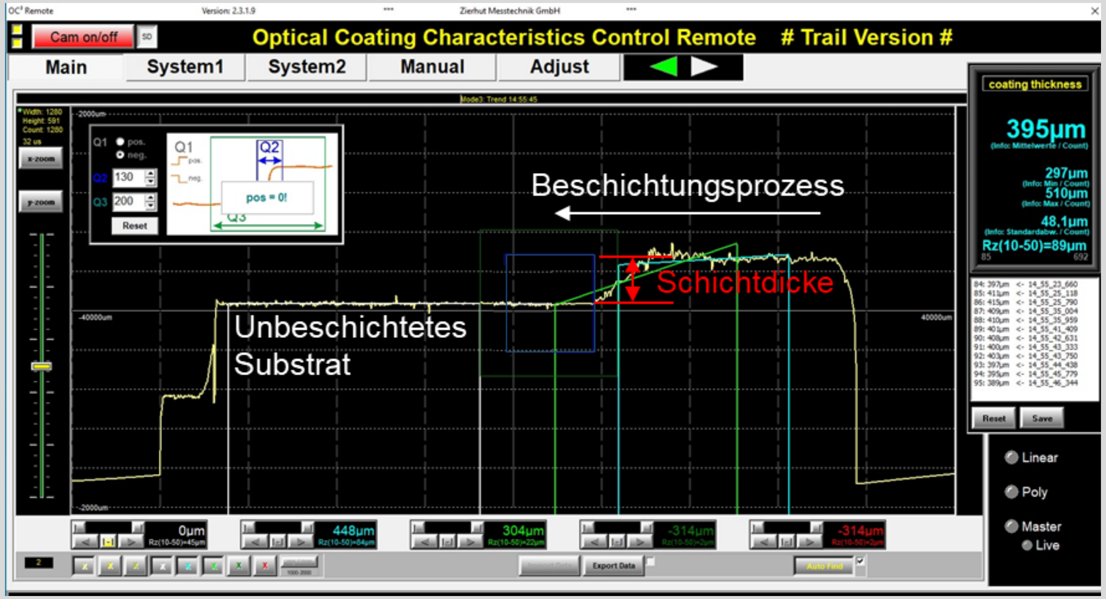
- Offline 3D powder stream analyses based on sheet laser illumination of inflight particles
- Evaluation of powder feed line and nozzle condition
- Automatic determination of characteristic factors

Process monitoring and control tools

- Online powder stream analyses based on sheet laser illumination of inflight particles
- Detection of blocked feed lines, pulsing powder flow and change of powder stream geometry
- Plasma formation over melt pool requires lateral camera images

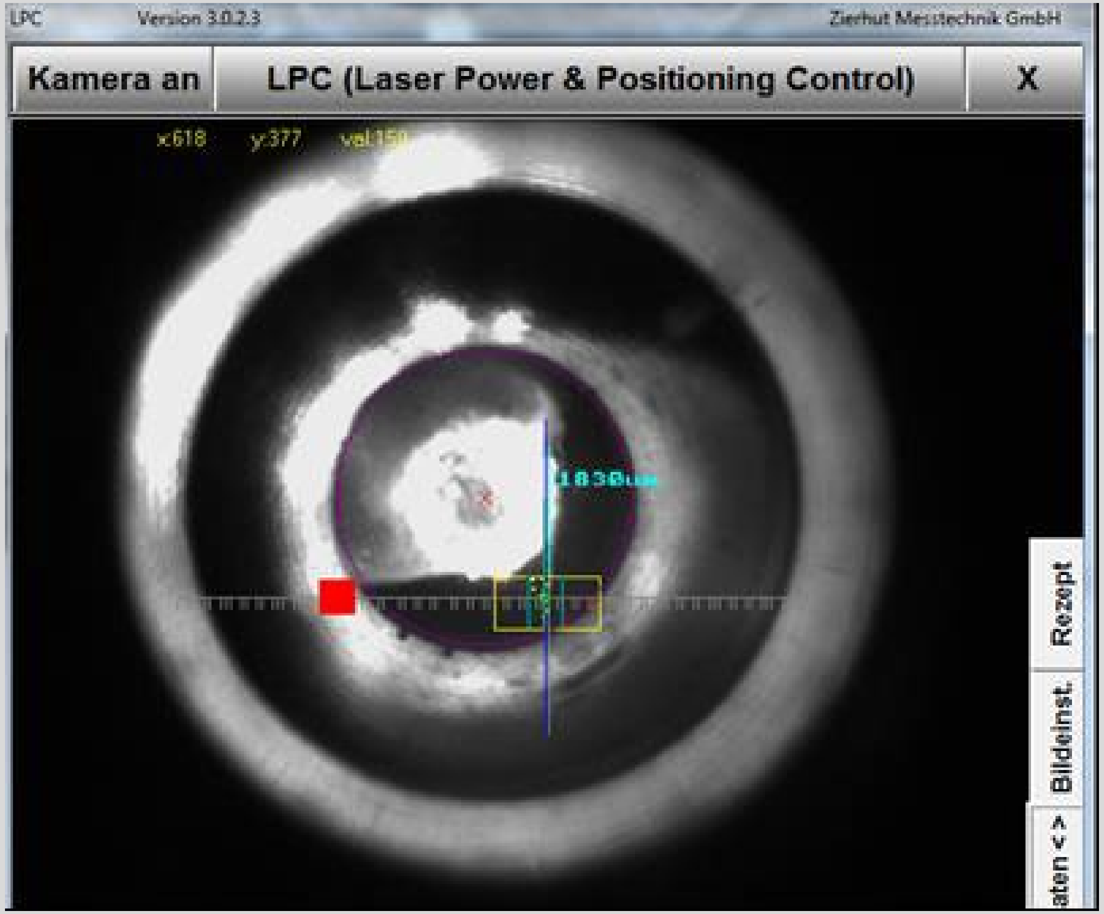
Process monitoring and control tools

- Online layer thickness monitoring based on laser triangulation sensor (7 µm accuracy)
- Difference of plain distances in front of and behind melt pool
- Online detection of crater formation possible



Process monitoring and control tools

- Optimal cladding of friction ring edges based on edge position detection
- Weighing of discs after deposition of individual layers
- Offline determination of laser power by calorimetry



Continuous process improvement

- Workpiece specific process and feedstock data from all processing steps combined with evaluation by (non-)destructive testing permits:

- fine tuning of process limit values for secure detection of faulty workpieces

- fine tuning of feedstock specification

- adaptation of process parameters depending on feedstock properties