Tailoring of workpiece geometry and coating microstructure in laser cladding processes

Andreas Wank
Emporia, Aachen, May 16th - 17th, 2023
• 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 / W₂C/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$_2$C/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 Al₂O₃ 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 (/ W₂C/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

<table>
<thead>
<tr>
<th>production route</th>
<th>feed stability</th>
<th>dilution in matrix</th>
<th>carbide crack resistance</th>
<th>cladding strength</th>
<th>availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>leached</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>--</td>
</tr>
<tr>
<td>sintered and crushed</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+(+)</td>
</tr>
<tr>
<td>agglomerated and sintered composite</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>0</td>
<td>+(+)</td>
</tr>
<tr>
<td>sintered and crushed composite</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+(+)</td>
</tr>
<tr>
<td>plasma spheroidized</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
Particle density distribution influence

- Control of local particle density permits influence on local laser interaction with substrate / previous cladding layer surface.
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, FTCs 2x 4 l/min

Carrier gas Ar, FTCs 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

<table>
<thead>
<tr>
<th>welding strategy</th>
<th>avg. distortion towards CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI (io, oi, io)</td>
<td>100,0%</td>
</tr>
<tr>
<td>CO (io, oi, io)</td>
<td>95,8%</td>
</tr>
<tr>
<td>CI (oi, io, oi)</td>
<td>32,8%</td>
</tr>
<tr>
<td>CO (oi, io, oi)</td>
<td>27,8%</td>
</tr>
<tr>
<td>CI (io, oi, io)</td>
<td>17,0%</td>
</tr>
<tr>
<td>CO (oi, io, oi)</td>
<td>9,3%</td>
</tr>
<tr>
<td>CI (io, io, io)</td>
<td>-12,8%</td>
</tr>
</tbody>
</table>
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
Influence of thermal history

- Surface appearance after AK Master dyno test
  - cladding of Cl, 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!

www.gtv-mbh.com
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