Optimizing components and surfaces with diode laser – generating, cladding and hardening of products

Dipl.-Ing. Markus Rütering, Laserline GmbH
Laserline - Overview

Laserline – Company

- Leading in multi kW high power diode lasers
- World wide active
  - Subsidiaries in China, USA, Japan, Korea
  - Distributors in several territories
- More than 3500 systems installed
- Founded in 1997
- Continuous growths over the last years
- 240 employees (Apr. 2016)
Change in Laser Technology

Product life cycle

Phase I: Development
Phase II: Introduction
Phase III: Market growth
Phase IV: Maturity
Phase V: Decline

Concept Creation
Diode Laser
Fiber Laser
Disk Laser
CO₂ Laser
LPSS

Concept Development
Market Development
Business Optimization
Harvesting

High power direct diode lasers are in the growing phase
Applications Overview

Additive Processes / Cladding

3D Printing
- High complexity parts
- 10x times faster than powder bed
- Also: hybrid machines

Wear and Corrosion Protection
- Strength and lifetime increase
- No pores or cracks
- Very low dilution
- Powder or wire
- High efficiency

Remanufacturing
- Cost and material savings
- Environmentally friendly
- In-situ or mobile

Surface Enhancement
- Non magnetic areas to avoid interference
- Local properties adjustment

Source: DMG Mori Seiki, Fraunhofer CCL, TM Comas, Technogenia © Laserline GmbH
Diode Lasers in cladding, generating and hardening

Outline

- Ultra high speed laser cladding
  - Motivation
  - Results
  - Outlook
- General Cladding applications
  - Examples and results
- Additive manufacturing at a glance
  - Results
- Laser hardening
  - Examples and results
- Summary
# Wear and corrosion protection

**Layer Thickness**

<table>
<thead>
<tr>
<th>µm</th>
<th>0,1</th>
<th>1</th>
<th>10</th>
<th>100</th>
<th>1000</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Technique</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition Welding</td>
<td></td>
</tr>
<tr>
<td>Laser Material Deposition</td>
<td></td>
</tr>
<tr>
<td><strong>Ultra High-speed LMD</strong></td>
<td></td>
</tr>
<tr>
<td>Thermal Spraying</td>
<td></td>
</tr>
<tr>
<td>Electroplating</td>
<td></td>
</tr>
<tr>
<td>CVD</td>
<td></td>
</tr>
<tr>
<td>PVD</td>
<td></td>
</tr>
</tbody>
</table>

Source: T. Schopphoven, Fraunhofer ILT
Conventional vs. Ultra High-speed LMD

Conventional LMD
Primary energy deposition into substrate
Particle temperature below melting temperature

Ultra-high-speed LMD
Primary energy deposition into powder
Particle temperature range of melting temperature

Source: T. Schopphoven, Fraunhofer ILT © Laserline GmbH
Ultra high-speed Laser Material Deposition machine

Schematic

Max. revolutions 2000 rpm
Max. length 1500 mm
Max. diameter Ø 300 mm
Fanuc CNC control
Camera monitoring
Laserline 2”-optic
Laserline 4 kW laser source

Source: T. Schopphoven, Fraunhofer ILT © Laserline GmbH
Ultra-High-Speed LMD vs. Conventional LMD

### Resource Consumption

<table>
<thead>
<tr>
<th></th>
<th>Conventional LMD</th>
<th>Ultra-High-Speed LMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material…</td>
<td>843</td>
<td>373</td>
</tr>
<tr>
<td>Time [min]</td>
<td>105</td>
<td>18</td>
</tr>
<tr>
<td>Costs [€]</td>
<td>270</td>
<td>70</td>
</tr>
</tbody>
</table>

- **Conventional LMD**
  - **Diameter:** Ø 50 mm
  - **Length:** 1 m
  - **Diameter:** Ø 50 mm

- **Ultra-High-Speed LMD**
  - **Diameter:** Ø 50 mm
  - **Length:** 1 m
  - **Diameter:** Ø 50 mm

### Assumptions

- **Ultra-High-Speed LMD**
  - \( v_v = 25 \) m/min
  - \( m_p = 21 \) g/min
  - \( s = 250 \) µm

- **Conventional LMD**
  - \( v_v = 1.5 \) m/min
  - \( m_p = 8 \) g/min
  - \( s = 500 \) µm

Source: T. Schopphoven, Fraunhofer ILT © Laserline GmbH
Ultra High-speed LMD Example

- Deposition times and powder consumption for different layers
  - 250µm, 18min, 377g
  - 100µm, 7.2min, 150g
  - 50µm, 3.6min, 75g

Hydraulic Plunger

- Length: 1 m
- Diameter: Ø 50 mm

Source: T. Schopphoven, Fraunhofer ILT © Laserline GmbH
Ultra High-speed LMD

- **High speed** – feed rate 20 - 200 m/min, surface rate 50 – 500 cm²/min

- **High quality** – fully metallurgical bonded layers, 25 - 250 µm thickness, < 1% dilution

- **Resource efficiency** – less laser power, less powder consumption compared to conventional LMD
Example for Surface Qualities

Surface as deposited

Laser remelted surface

Source: T. Schopphoven, Fraunhofer ILT © Laserline GmbH
Additive Manufacturing - Heat sensitive substrates

**Shaft tunnel micro gas turbine**

**Parameters**
- Deposition time approx. 7.2 min
- Single layer thickness approx. 110 µm
- Hardness 300 HV0.3

**Cross-sections**
- Wall thickness 1 mm
- IN 625 on stainless steel
- Crack-free

Source: T. Schopphoven, Fraunhofer ILT © Laserline GmbH
Unconventional Material Pairings
MMC on grey cast iron

Cross-section

Results

- 1:1 wt.-% | WC : IN625
- Dilution < 1 %
- Single layer thickness approx. 60 µm

Disc brakes

- Diameter: Ø 300 mm

Source: T. Schopphoven, Fraunhofer ILT © Laserline GmbH
Ultra High Speed Cladding

Summary

- **HIGH - SPEED LMD**
  - Minimize time for powder to melt in the melt pool
  - Deposition of laser energy primary into the powder
  - Deposition speed up to 200 m/min comparable to thermal spray and hard chrome plating
  - Deposition rate up to 1.5 kg/h
  - Surface rates up to 3 m2/h
  - Layer thickness in the range of 10 - 250 µm
  - Penetration depth < 5 µm
  - Scatter of layer thickness in the range of 54 µm
Diode Lasers in cladding, generating and hardening

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Laser Equipment for Cladding

Equipment

- **Diode Laser**
  - LDF or LDM
  - Mobile and flexible unit
  - Suitable Laser power
  - Integrated pyrometer

- **Complete Optics**
  - Fiber-coupled
  - 1” and 2” Optics

- **Customized Spot**
  - Homogenized laser focus
  - Lines, rectangles and squares

- **Accessories**
  - Special process Optics
Laser Cladding Basics

Influence of Intensity profile: Gauss vs. Top-hat

- Small energy input
- Low dilution by melting of base material
- Higher efficiency at same laser power
- Overheating of the melt at centerline
- Increased burn-in in middle of track
- Larger dilution of cladded material
- Larger dilution of cladded material

Laser Equipment for Cladding

COAXwire – Laser cladding with wire feeding

Increase of abrasive wear and corrosion resistance

- Optical system: 1" optics (OTS-1)
- Laser power: up to 4 kW
- Beam quality: < 30 mm/mrad, NA 0.1
- Spot size: ~ 1.8 mm
- Material: nickel-, cobalt-, iron-based alloys (0.8 – 1.6 mm)
- Deposition rate: 0.5 m²/h; 250 cm³/h

Main advantage: no waste material in comparison to cladding with powder
Future developments in laser cladding

High Power Cladding with 20 kW

<table>
<thead>
<tr>
<th>COAX Powerline (circular spot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser power: 20 kW</td>
</tr>
<tr>
<td>Feed rate: 3900 mm/min</td>
</tr>
<tr>
<td>Powder feed rate: 250 g/min</td>
</tr>
<tr>
<td>Cladding rate: 1,76 m²/h</td>
</tr>
<tr>
<td>Deposition rate: 14,72 kg/h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COAX 11 V3 (rectangular spot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser power: 20 kW</td>
</tr>
<tr>
<td>Feed rate: 1540 mm/min</td>
</tr>
<tr>
<td>Powder feed rate: 250 g/min</td>
</tr>
<tr>
<td>Cladding rate: 1,17 m²/h</td>
</tr>
<tr>
<td>Deposition rate: 14,25 kg/h</td>
</tr>
</tbody>
</table>
Cladding Examples

Downhole Drilling: Process Example

- WC/Co + NiCrBSi on steel
- Only NiCrBSi matrix is molten
- 50% (typ 63%) volume content of coarse-grained carbides
Cladding Examples

Downhole Drilling: Parts

- Stabilizers
  - Stabilize the drilling tool against the drill hole wall
  - “Wing” geometries generate channels for removal of drill fluids and earth material
  - Multidirectional cladding required

Source: Laser Welding Solutions
Cladding Examples

Laser cladding of rollers in steel industry

- Various different Rollers for steel industry
Cladding Examples
Laser cladding of rollers in steel industry

- Laser cladding system for rotary parts
- System Technology from RH CNC, Anyang China
- Maximum Length about 10 m
- Laser power up to 10 kW today
- Up to 16 kW Laser possible
- Various powders, thicknesses, hardness possible
Cladding Examples
Forming Tools

Cross-section Stellite21 on GGG40

Example:
Tool for plastic material processing

Source: Fraunhofer IWS
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Repair Welding Examples

Additive Manufacturing already?

Source: TM Comas
## Cladding Process Basics

### Differences of Cladding and Additive Manufacturing

<table>
<thead>
<tr>
<th></th>
<th>Cladding</th>
<th>Additive Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>main aims</strong></td>
<td>• layer properties (e.g. hardness)</td>
<td>• build-up of complex geometries</td>
</tr>
<tr>
<td></td>
<td>• deposition rate</td>
<td>• repair of worn out parts</td>
</tr>
<tr>
<td><strong>additional material / base material</strong></td>
<td>dissimilar</td>
<td>similar</td>
</tr>
<tr>
<td><strong>used materials</strong></td>
<td>abrasiv-, corrosion-resistance materials, particle reinforcement</td>
<td>superalloys (nickel-, cobalt- and titanium-based)</td>
</tr>
<tr>
<td><strong>number of layers</strong></td>
<td>&lt; 5</td>
<td>&gt; 50</td>
</tr>
<tr>
<td><strong>dilution rate [%]</strong></td>
<td>&lt; 10</td>
<td>&gt; 10</td>
</tr>
<tr>
<td><strong>spot diameter [mm]</strong></td>
<td>&gt; 4</td>
<td>&lt; 4</td>
</tr>
<tr>
<td><strong>laser power [kW]</strong></td>
<td>&gt; 3</td>
<td>&lt; 3</td>
</tr>
</tbody>
</table>
Powder Inconel 625

Future Work: High power laser build up cladding

- Build up cladding with high laser power up to 20 kW is possible!
- Build up rate ~ 30 cm³/min
- Laser power regulation system is required
- Overheating is a problem especially on smaller geometries
  - Heat input is higher as the thermal conduction in the part
Repair Welding Examples

Laser Repair of Blade Tips: Introduction

- Blade tips create a seal against housing
- Tight seal generates wear over time as engine temperatures change
- Blade tips engineered to be worn out
- Blade tip rework more economical than replacement

Source: IREPA
Repair Welding Examples

Laser Repair Welding of Turbine Blades

Base material: CM 186
Added material: Inconel 738

Base material: Inconel 625
Added material: Inconel 738

0.180” x 0.050”
Future developments in laser cladding

Additive Manufacturing

Repair of gas turbine blades by laser cladding

- Commonly used materials: nickel- / cobalt-based superalloys
- Process requirements
  - Laser spot size adapted to geometry (typical 0.5 – 1.5 mm)
  - Use of coaxial nozzles to achieve good shielding of treatment area (< 30 ppm O₂)
  - High powder efficiency of nozzle to reduce material costs (typical > 90%)
Laserline Strategy
Future growing new Markets

3D-Printing in metals

- Laser-assisted milling and cladding in one machine
- 2-6 kW diode laser
- Opens the door for generative production for huge elements, e.g. aircraft industry
- Several ten machines in the market
Additive Manufacturing Examples

- 3D contour
- 100% build from powder
- 3D contour
- 100% build from powder
- 3D contour
- 100% build from powder
- 3D contour
- 100% build from wire
Drivers of AM

Future drivers for AM

- Improved process parameters for standard machines
- Further machine concepts to reduce cost and down times
- New machine concepts in development
- Reduction of cost for machines with
  - More competition
  - Scaling effects with more machines build
  - Reduced cost for new machine concepts
- Cost reduction in powder
  - Due to higher consumption
  - New production technologies
  - More competition
- More knowledge available
  - Operators
  - Designers
  - Customers
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Main Heat Treatment Technologies

Overview

- **Oven**
  - Heating of the complete part
  - Limited size of the workpiece
  - High distortion, warpage

- **Flame**
  - Manual process
  - No temperature control
  - Poor repeatability

- **Induction**
  - Post-processes required
  - Additional cooling required
  - Most closely matches laser hardening
  - Almost no further finishing process required

- **Laser**
  - Closed-loop temperature control
  - Homogeneous and constant case depth

Source: Erlas
Main Heat Treatment Technologies

Process Chain: Induction vs. Laser hardening

- Less mechanical wear of costly machining tools
- Reduced process time
- Less process steps

→ 20% overall cost reduction possible.
Applications and Examples

Steering rack

- Laser power: 3.500 W
- Spot: 10 x 25 mm²

Source: Matex
Applications and Examples
Forming: Increased ductility of high strength metal sheets

- Hot-stamping produces fully martensitic part
- LHT (Laser heat treatment) to locally increase ductility
- High strength part, but ductile in a desired zone

Tensile strength ~ 1500 MPa
Max. elongation ~ 5%

Tensile strength down to 600 MPa
Max. elongation up to 25%
Diode Lasers in Cladding, generating and hardening applications

Summary

- Diode laser technology is still growing fast and offers new opportunities
- Laser metal deposition is well known but still offers a lot of options
- Applications based on wire vs. powder are moving into industry right now
- Additive manufacturing is in its early stage of its life cycle
- Laserline is leading company in high power diode lasers
- Hardening by laser is known but not utilized as possible
- Visit us on our booth here in Lasys