Laser cladding with high power – a review of the Trilaser project

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Presentation outline

  - Background information & starting points
  - Goals & objectives
  - Targets for development (Work packages)
  - Results
- Summary & Outlook
Personnel

- Petri Vuoristo (TUT), Professor
- Jari Tuominen (TUT Kokkola), Project Manager (Part time; 50%)
- Jonne Näkki (TUT Kokkola / KETEK (80/20%), Researcher
- Henri Pajukoski (TUT Kokkola), Researcher

Also Tuomo Peltola (KETEK), Jorma Vihinen (TUT), Jyrki Latokartano (TUT), Juha Junkala (KETEK), Juha Nissi (KETEK), Mikko Kylmälahti (TUT)
Background information and starting points for Trilaser-project

- Laser cladding is currently done with 3 – 6 kW lasers (CO$_2$, Nd:YAG, HPDL) (some ~20 kW CO$_2$ large area cladding applications exist; boiler tube panels, piston rods for hydraulic cylinders)
- Low electrical and process energy efficiencies, mirror guidance, (~20 kW CO$_2$)
- New type of lasers 10 – 50 kW available (disc and fiber lasers)
- High electrical and process energy efficiencies, low maintenance and operating costs, rather small size, beam transported via fibres
- Laser cladding with these new devices still totally unknown area (15 – 50 kW)
Some high power cladding applications (CO$_2$)

Praxair Surface Technologies, USA
Waterwall tube panel
25 kW CO$_2$

Swanson Industries, USA
Piston rods, rolls
20 kW CO$_2$

AeroMet Corp., USA
Near net shape 3D for aerospace
18 kW CO$_2$
(does not exist anymore)
Lasers available for cladding and their properties

<table>
<thead>
<tr>
<th></th>
<th>Fiber</th>
<th>Nd:YAG</th>
<th>CO2</th>
<th>Disc</th>
<th>HPDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall-plug efficiency*</td>
<td>30%</td>
<td>~3% (Ip)</td>
<td>~10% (FAF)</td>
<td>20-28%</td>
<td>35-45%</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1.07μm</td>
<td>1.06μm</td>
<td>10.6μm</td>
<td>1.03μm</td>
<td>808-1030nm</td>
</tr>
<tr>
<td>Beam guidance</td>
<td>Fiber</td>
<td>Fiber</td>
<td>Mirror</td>
<td>Fiber</td>
<td>Fiber</td>
</tr>
<tr>
<td>Footprint</td>
<td>1.2m² (20kW)</td>
<td>3.2m² (4kW)</td>
<td>5.7m² (20kW)</td>
<td>3.9m² (16kW)</td>
<td>0.3m² (6kW)</td>
</tr>
<tr>
<td>Footprint (chiller)</td>
<td>1.2m² (20kW)</td>
<td>3.1m² (4kW)</td>
<td>3.0m² (20kW)</td>
<td>2.0m² (16kW)</td>
<td>0.4m² (6kW)</td>
</tr>
<tr>
<td>Max. power</td>
<td>30kW</td>
<td>6kW</td>
<td>20kW</td>
<td>16kW</td>
<td>15kW</td>
</tr>
<tr>
<td>Mobility</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Operating costs</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

*External chiller not taken into account
Goals & objectives

Main goals

- To define industrial applicability of new high power lasers in cladding
- To increase productivity considerably
- To achieve coating quality similar to those currently produced with existing laser cladding technologies (low dilution, segregation etc.)
- To develop cladding tools which withstand extraordinarily high powers
- To enlarge the field of laser cladding applications

Sub-goals

- To design and implement mobile cladding unit for on-site repairs
- To develop quality assurance of process itself and powder, wire and strip consumables
- To test newly developed coaxial wire cladding heads
- To develop deep understanding of high power laser cladding processes (simulation, modelling?)
Targets for development (WPs)

Clad quality (metallography)
- Dilution, segregation, porosity, cracking, bonding defects etc.

Clad performance
- Wear, corrosion, fatigue

Cladding with high laser power (>10kW)
- Powder, wire, strip (cold, hot), process optimization

Modern cladding tools
- Availability, testing (powder, wire, strip)
- Development of tools for high power

Trilaser – Cladding & Surface Treatments

Economical feasibility
- Evaluation

On-site cladding
- Market study, conceptual design of mobile cladding unit, implementation, applications

Quality assurance & control
- Process, consumables

Consumables
- Powder, wire, strip

Monitoring & imaging
- Real time process control, high-speed imaging

Hardware (hot-wire)
- Failure & wear analyses, development of wire & gas nozzle, driving wheel etc.
Laser cladding with high power levels (HPDL)

Fraunhofer IWS, Germany
10 kW HPDL fiber coupled
80 kW induction
Coax 11
Off-axis
9.2 kg/h
14.5 kg/h (with induction)
Laser cladding with high power levels (disc)

Fraunhofer ILT, Germany
RWTH Aachen, Germany
10 kW Yb:YAG disc (300µm fiber)
Zoom optic for variable spot
Coaxial ILT 3-jet nozzle for circular beam
Off-axis nozzle for square beam
4.6 kg/h (5.25 kW)
Laser cladding with high power levels (fiber)

ARL Penn State, USA
12 kW fiber laser
1D-scanner (20-30Hz) (water-cooled Cu mirror)
Off-axis nozzle

<table>
<thead>
<tr>
<th>Material:</th>
<th>Inconel 625 on HY-80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition Rate:</td>
<td>11.4 kg/hr</td>
</tr>
<tr>
<td>Travel Speed:</td>
<td>0.5 m/min</td>
</tr>
<tr>
<td>Laser Power:</td>
<td>10 kW</td>
</tr>
<tr>
<td>Scan Width:</td>
<td>25 mm</td>
</tr>
</tbody>
</table>
Laser cladding with high power levels (HPDL)

Developments in Deposition Rates

<table>
<thead>
<tr>
<th></th>
<th>Deposition Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year 2000 typical deposition rates with 8kW CO₂ laser</strong></td>
<td></td>
</tr>
<tr>
<td>Hardfacing*</td>
<td>10.2 lbs/hr (4.6 kg/h)</td>
</tr>
<tr>
<td>Inconel 625</td>
<td>5.1 lbs/hr (2.3 kg/h)</td>
</tr>
<tr>
<td><strong>Today’s achievable rates with 8kW solid state lasers</strong></td>
<td></td>
</tr>
<tr>
<td>Hardfacing*</td>
<td>25.3 lbs/hr (11.5 kg/h)</td>
</tr>
<tr>
<td>Inconel 625</td>
<td>11.0 lbs/hr (5.0 kg/h)</td>
</tr>
<tr>
<td>**Hybrid Cladding Developments (Laser Hot Wire a.o. <strong>)</strong></td>
<td></td>
</tr>
<tr>
<td>Inconel 625</td>
<td>22-33 lbs/hr (10-15 kg/h)</td>
</tr>
</tbody>
</table>

* 60% (Mass) Tungsten Carbide in Ni-Base Matrix
** may not be useful for some applications

LWS Laser Welding Solutions, Houston, USA
Swanson Industries Expands Laser Cladding Services To Deliver Superior Corrosion Protection

Swanson Industries recently expanded its laser cladding services to accommodate components weighing up to 40,000 pounds and measuring up to 80 feet in length and 60 inches in diameter.

FOR IMMEDIATE RELEASE

PRLog (Press Release) - Jun 06, 2011 -
Swanson Industries, a worldwide distributor and supplier of hydraulic, machining, remanufacturing, plating, recently expanded its laser cladding services to accommodate components weighing up to 40,000 pounds and measuring up to 80 feet in length and 60 inches in diameter. The new 80-foot long jetline laser workstation and 12kw laser provides corrosion protection that significantly increases the life span of components.

"The new laser system uses fiber optic cables which save time, energy and money," said Mark Carter, Vice President of Business Development, "and that’s a savings we pass on to the customer."
Beam forming/shaping

- Fiber & disc lasers; excellent beam quality -> very high power densities
- In laser cladding NOT very high power densities required (100-1000W/mm$^2$)
- Laser beam spot needs to be expanded:
  - By defocusing with standard welding optics
  - By oscillating mirrors (scanners)
  - By homogenizing optics (integrating mirrors, group of lenses)

![Graph showing power density vs. interaction time for different laser types.](image)

- Not optimal for cladding!
Beam forming/shaping (scanners)

- Large and homogeneous beam profiles required in cladding
- Rectangular beam profiles by scanners
- Based on galvanometrically driven or direct motor driven oscillating water-cooled mirror (spring)
- Sinus, triangular, square waveforms
- Power can be adjusted along scanning line
- Unique custom energy profiles
- Water cooled mirrors (~30 kW)
Beam forming/shaping (optics)

- Cylindrical collimator (Optoskand)
- Circular prism integrators (HighYAG)
- Facetted integration elements (HighYAG)
- Integrating mirrors (Kugler, Scansonic)
- Some requirements: ability to withstand high power levels, low focus shift & power loss, long working distance preferred due to back reflection

Homogenized rectangular spot (HighYAG)

Multi-facetted mirror (Kugler)
Laser cladding with high power levels (fiber)

St. Petersburg State Polytechnical University
Institute of Laser and Welding Technologies
15 kW Yb fiber laser (IPG Photonics)

Scanner cladding with powder (Stellite 6, Inconel 625)
Linear traverse cladding with wire (316L, Inconel 625)
Scanner cladding with 15 kW fiber laser

Inconel 625

P = 15 kW
v = 750 mm/min
Ø = 5 mm
f = 315 g/min
Frequency 100 Hz (Triangular)
Inter-track advance 9 mm
Coating width 37 mm
Max. coating height above substrate 4.2 mm
Deposition rate 15.6 kg/h
Powder catchment efficiency 79%

~1.8 wt.% Fe

~4 wt.% Fe

15 kW, 1000 mm/min, 273 g/min, inter-track advance 10 mm

Coating

Depth (mm)
Linear traverse cladding with 15 kW fiber laser (wire)

Geometrical dilution: 19.3%

\[ P = 14.75 \text{ kW} \]
\[ v = 1000 \text{ mm/min} \]
\[ \varnothing = 10 \text{ mm} \]
Wire feed 5.5 m/min (93 g/min)
Wire \( \varnothing = 1.6 \text{ mm} \)
Inter-track advance 5 mm
Total cross-section 59.9 mm\(^2\)
\[ \rightarrow 7.4 \text{ kg/h} \]

Inconel 625
### Corrosion studies for scanner clad coatings

<table>
<thead>
<tr>
<th>Mass loss (mg)</th>
<th>Laser</th>
<th>Hard-chrome</th>
<th>Wrought</th>
<th>PTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>625 laser (69)</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>625 wrought</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>625 laser (68)</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>625 PTA</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>316L wrought</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2xhard-chrome + 316L laser coating on mild steel</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2xhard-chrome on mild steel</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Exposure of coating surface to 6% FeCl₃ + HCl solution for 72 hours in oven set to 70°C
- Area between test specimen and corrosion cell was sealed with PTFE gasket
- Prior to tests laser coatings were milled on a Makino A55 CNC milling machine and ground with 600/1200 SiC paper
Wear studies for scanner clad coatings

- Pin-on-disc type sliding wear tester (CETR UMT-2)
- $F = 62N$, $v = 2400\text{mm/min}$, $t = 6h$, $s = 864m$
- Dry conditions at RT
Deposition rates

![Graph showing deposition rates against laser power. The graph includes data points for CO2, Nd:YAG, HPDL, Fiber, Disc, Induction, Hot-wire, Powder scanner cladding, and Cold-wire linear traverse cladding.](image-url)
Strip laser cladding with high power levels

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Alloyed &amp; Hardfacing</td>
<td>410 NiMo, 420, etc.</td>
</tr>
<tr>
<td>Stainless Steels</td>
<td>308 L, 316 L, 347, etc.</td>
</tr>
<tr>
<td>Cobalt Alloys</td>
<td>Co alloy 6, Co alloy 21, etc.</td>
</tr>
<tr>
<td>Nickel Alloys</td>
<td>825, 625, 600, 400, etc.</td>
</tr>
</tbody>
</table>
Strip cladding with scanner

4.4 kW YAG, YW50 (f = 500 mm), ILV DC-Scanner
4.4 kW, 72 mm/min, strip feed 37 g/min, scan width 40%, frequency 20 Hz, Triangular scan form

316L strip (w = 30 mm, t = 0.5 mm)
Strip cladding with scanner

- OK Band 316L
- Soudotape 420
- Duplex 2209
- Soudotape 625

~0.5m

35-55°

45-60°
Strip cladding with scanner

Top view

Side view
Modern cladding tools

Mitsubishi

Arnold

Cavipro

Precitec

HighYAG

Dimensions: 400 × 100 × 100 mm
Weight: 5 kg
Rate of Magnification: × 1

Optical fiber
MIG wire-feeding unit
Adjusting screw
Beam focusing unit

Powder nozzle
Laser beam cone
Shielding cone

Diode laser sectors

130 mm
220 mm

Wire Feeding Lead
CCD-Kamera
Adaptation

Zoom Collimation
Adjustable Beam Splitter
Beam Bending and Focusing
Cover Slide
Wire Adjustment

jari.tuominen@tut.fi
Laser Coating Seminar
Kokkola 16.2.2012
Coaxial cold- and hot-wire tests at IWS

- Rofin (dp) Nd-YAG 4.4kW
- HighYAG coaxial wire cladding head
- DINSE wire feeder DIX WD 300
  - Water cooled wire nozzle
  - Coaxial gas shielding
- DINSE Dix WDE 315 control unit
- DINSE monitoring software
- DINSE Dix DLS 200 wire monitoring unit
- Kemppi Master MLS2500 (MMA/TIG) (160A at 100% duty cycle)

Wires:
- Inconel 625 Ø=1.0mm (solid)
- Duplex 2509 Ø=1.2mm (solid)
- 414G Ø=1.2mm (tubular)
- Stellite 21 Ø = 1.2mm (tubular)
Coaxial hot-wire cladding tests at IWS

IN-625 ; 3.5kW, 2500mm/min, 150A, 5V, inter-track advance 1.3mm, overlapping 55%, dilution 11%, 2.3kg/h

Duplex; 3.5kW, 2500mm/min, 150A, 5V, inter-track advance 1.3mm, overlapping 55%, dilution 3.2%, 2.5kg/h

414G; 3.5kW, 3000mm/min, 0A, 0V inter-track advance 1.4mm, dilution 9%, 2.5kg/h
Coaxial hot-wire cladding tests at IWS

Inconel 625 hot-wire (3kW, 3000mm/min, 150A, 5V)

414G cold-wire (3kW, 3000mm/min)
Coaxial cold-wire cladding tests at IWS

AASS – test Acetic Acid Salt Spray
ISO 9227 / ASTM B287
2000h test in progress
5 wt.% NaCl, 35°C, pH ~3

Vötsch SC 1000 salt spray test chamber

Inconel 625 on mild steel
D50

Inspection ~800h
-> no signs of corrosion
Quality and process control

- Coating quality (hot cracks, dilution) strongly dependent on powder (In625)
On-site repairs and cladding

- Mobile cladding units transported to the components
- Cost efficient solution (high value massive components, disassembly & transportation to nearest cladding job shop causes too long shutdown, is affixed or welded to some complex systems etc.)
- Applications in oil & gas drilling platforms, paper mills, steel plants, nuclear power plants, shipyards, ships, turbine power stations
On-site repairs and cladding

- LaserAge Ltd, Ireland, 2 kW HPDL, 3 linear axes, 1200kg
- Stork Gears & Services BV, the Netherlands, HPDL+robot
- NedClad, the Netherlands, HPDL+robot
- Duroc, Sweden, 4 kW fiber + robot, 2500kg
- ARL Penn State, USA, fiber laser repair cell for Vertical Launch System

jari.tuominen@tut.fi Laser Coating Seminar Kokkola 16.2.2012
On-site repairs and cladding
On-site repairs and cladding

Stork Gears & Services BV, the Netherlands, HPDL+robot
On-site repairs and cladding

- 10kW fiber laser + chiller + robot
- Powder & wire feeders + coaxial nozzles
- Floor mounted tracks & carrier
- Positioner + tailstock
- Laser safety curtain

→ Cladding can take place inside and outside container

"Transportable Laser Cladding System" by J. Hakala, Y. Guo, D. He (TTE-5107 Design of Robot Systems)
Summary & Outlook

- New type of lasers 10 – 50 kW available (disc and fiber lasers)
- High deposition rates (up to 16-17 kg/h) with 15 kW fiber laser + scanner (powder cladding)
- Fusion bonded coatings with low dilution
- Long-term cladding operation needs to be tested
- Possibility to use strip consumables + additional heat source
- Coaxial hot-wire cladding process was implemented with low power welding source -> high process stability
- Coaxial hot-wire cladding tests will be continued with higher power capacity welding source (300A/100%)
References

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Thank you for your attention!
Trilaser 2009-2013 – Laser processing with high power

- New type of lasers 10–50 kW available (disc and fiber lasers)
- Would it be possible to achieve excellent coating quality with considerably higher productivity?
- To bring some high power (>30kW) technology to Finland
- In cooperation with:
Fatigue durability of laser clad components

• Tampere University of Technology, Technology Centre KETEK Ltd., Luleå Technical University and CENTRIA research unit of the Central Ostrobothnia University of Applied Sciences conduct the project related to mechanical fatigue of laser clad components

• Project is funded by EU’s Interreg IV A North program

• Project duration is 2 years

• Total budget 455 kEUR

• Companies benefiting the project include end users of laser coatings (large diesel engines, power transmission components, hydraulic cylinders, pulp and paper handling equipment) and laser cladding workshops, also for those who want their end products to be qualified and proved by official classification societies

• Project includes testing under various forms of fatigue (axial, torsional and bending) using exceptionally large forces and FEM modelling

\[ y = 1933.7x^{-0.138} \]

\[ R^2 = 0.9897 \]