Laser Solutions Short Courses

Short Course #4
Laser Additive Manufacturing

Aravind Jonnalagadda and Siegfried Scharek
Course Instructors

Sunday, October 23 • 1:30PM
Room: Salon VI
A Short Course in Laser Cladding

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Presentation Overview

• Fundamentals of laser cladding
• Laser cladding vs. competing coating technologies
• Equipment
  – Laser
  – Optics
  – Cladding nozzles
• Cladding materials
• Applications and metallurgical review
• Future trends
Fundamentals of Laser Cladding

‘Laser Cladding is a process in which the coating material is metallurgically bonded with the substrate material using laser energy’

Video demonstrating laser cladding
Fundamentals of Laser Cladding

Typical single layer thickness: 0.2 – 2.0 mm

Heat input in part: Low – moderate

Dilution with substrate material: less than 5%

Adhesion: Metallurgical boning

Structure: Completely dense

Base Materials: Carbon steel, alloyed steel, stainless, cast iron, nickel alloys

Coating Materials: Fe-, Co-, Ni-alloys, metal / ceramic mixtures
Important attributes of a coating process

- Dilution (Measure of ‘Fe’ pickup from the substrate)
- Substrate-Coating bond (Metallurgical/Mechanical)
- Heat input into the part
- Thickness of the deposit / deposition rates
- Quality of deposit (porosity/cracks etc)
Laser cladding vs. other thermal coating techniques

Conventional coating techniques

- Thermal Spray Coatings
- Plasma Transferred Arc Cladding – PTA Cladding
Thermal Spray

Thermal Spray is a coating process in which metallic or non-metallic materials are deposited in a molten or semi-molten condition at high velocities to form a coating.

**Coating thickness:** 50-500 µm  
(0.002” -0.02”)

**Type of bond:** Mechanical

**Dilution:** N.A – due to mechanical bond

**Coating material types:** Metals and ceramics

Picture courtesy: Sulzer Metco
Thermal Spray

Picture courtesy: Stellite

HVOF sprayed NiCrBSi
Thermal Spray Summary

Benefits

1. Crack free coatings in high hardness materials
2. Ability to clad extremely thin coatings
3. Low heat input into the part

Disadvantages

1. Higher porosity content
2. Possible coating delamination – due to low bond strength
3. Low deposition thickness
4. Tensile or compressive residual stresses in the coating
Plasma Transferred Arc Cladding

Coating thickness: 0.5 - 5 mm (0.02” - 0.2”)

Type of bond: Metallurgical

Dilution: 5 - 15%

Coating material types: Metals and ceramics
PTA Cladding

Cross-section of sample clad with Stellite 6 using PTA
## Summary

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. High coating thickness and high deposition rates</td>
<td>1. High dilution</td>
</tr>
<tr>
<td></td>
<td>2. High heat input to the part</td>
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</table>
## Summary

<table>
<thead>
<tr>
<th></th>
<th>Thermal Spray</th>
<th>PTA</th>
<th>Laser Cladding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat source</strong></td>
<td>Gas flame</td>
<td>Electric arc</td>
<td>Laser beam</td>
</tr>
<tr>
<td><strong>Coating Thickness</strong></td>
<td>0.05 – 0.5 mm</td>
<td>0.5 - 5 mm</td>
<td>0.1 – 2 mm</td>
</tr>
<tr>
<td><strong>Deposition Rates</strong></td>
<td>≤ 40 lb/h</td>
<td>≤ 24 lb/h</td>
<td>≤ 12 lb/h</td>
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<tr>
<td><strong>Dilution</strong></td>
<td>0</td>
<td>5-15%</td>
<td>≤ 5 %</td>
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<tr>
<td><strong>Type of Bond</strong></td>
<td>Mechanical</td>
<td>Metallurgical</td>
<td>Metallurgical</td>
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<tr>
<td><strong>Bond Strength</strong></td>
<td>≤ 80 MPa</td>
<td>≤ 800 MPa</td>
<td>≤ 800 MPa</td>
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<tr>
<td><strong>Heat Input</strong></td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
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<tr>
<td><strong>Porosity</strong></td>
<td>≤ 5 %</td>
<td>100 % dense</td>
<td>100% dense</td>
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</table>
Comparison of three techniques

**HVOF Coating**
Coating material: **NiCrBSi**

**PTA Clad**
Coating material: **Stellite 6**

**Laser Clad**
Coating material: **Inconel 625**
Micro-structures

Microstructure of thermal sprayed Titanium oxide

Microstructure of Laser Clad Inconel 625
Laser Cladding Equipment

Cladding System Components

- Power source (Laser)
- Power delivery (Optic fiber or direct delivery)
- Optics
- Motion system
- Powder feeder
- Powder delivery nozzle
Laser Types

- Direct Diode laser
- Fiber laser
- Disc laser
- Fiber coupled diode laser
- Nd: Yag Laser
Optic Basics

The purpose of the optics is to modulate the light coming from the fiber to a required spot size for laser cladding.

Things to know:

• Numerical aperture
• Optic components: Collimator, Focusing lens
• Homogenizers and Special optics
• Optimal laser spot size for cladding
Optic Basics – Numerical Aperture

Numerical Aperture (NA) is the measure of angle of the laser beam coming out of the fiber

\[
NA = \sin \theta
\]

- Higher NA => High beam divergence
- Important factor in optic selection
Optic Basics – Numerical Aperture

Example

Fiber NA= 0.12

Collimator lens, \( f = 200 \text{ mm} \)

At NA= 0.22 the largest collimator lens we could use is \( f = 100 \text{ mm} \)

Fiber NA= 0.22

Collimator lens, \( f = 100 \text{ mm} \)

Based on data provided by Laserline Inc
Optic Basics – Optic Components

Spot diameter, \( d \) = \[ \frac{f_f}{f_c} \times f_d \]

Example:

\[ d = \frac{500 \text{ mm}}{100 \text{ mm}} \times 1 \text{ mm} = 5 \text{ mm} \]
Optic Basics – Special Optics

Homogenizers

• Special optic modules with faceted optics which generate uniform energy distribution across a shape such as square or rectangle

Scanners

• Scanning mirrors can generate a range of spot sizes and shapes

Rectangular focus spot

Scanning focus spot
Optics- Optic Head

- Collimator lens
- Camera viewing
- Focusing lens
- Protective glass
- XYZ adjustment
- Laser Cladding Nozzle
Optics- Laser Spot Size Determination

- Laser spot size is determined by the power density requirement

- Low power density
  => no surface melt
  - Spot > 10 mm x 10 mm

  Laser Hardening
  - Power density
  \( \sim 0.1 \times 10^4 \text{ watts/cm}^2 \) *
  * for steel substrates. Varies based on laser interaction time

- Medium power density
  => surface melt
  - Spot \( \phi \sim 5\text{mm} \)

  Laser Cladding
  - Power density
  \( \sim 1.5 \times 10^4 \text{ watts/cm}^2 \) *
  * for steel substrates. Varies based on laser interaction time and powder type

- High power density
  => key hole effect
  - Spot \( \phi < 0.5\text{ mm} \)

  Laser Welding
  - Power density
  \( \sim 100 \times 10^4 \text{ watts/cm}^2 \) *
  * for steel substrates. Varies based on laser interaction time
Optics- Laser Spot Size Determination

Example: How to determine the laser spot size?

• Available laser Power, \( P = 3 \) kW
• Power density, \( P_d = 1.5 \times 10^4 \) watts/cm\(^2\)
• Laser spot area, \( A = ? \)

\[
P_d = \frac{P}{A} \quad \Rightarrow \quad A = \frac{P}{P_d} = \frac{3000}{1.5 \times 10^4} = 0.2 \text{ cm}^2 = 20 \text{ mm}^2
\]

• Circular spot diameter, \( d = \sim 5 \text{ mm} \)
Cladding Nozzle

Importance of cladding nozzle
- High powder utilization efficiency
- Flexibility with beam sizes/
  Focal lengths
- Different Lasers
- Low in maintenance
- Long ON times
Types of Powder Nozzles

- Side Axis Nozzles
- Coaxial Nozzles
- Custom Nozzles
Side Axis Nozzle

Features

• Diffuser mechanism to reduce powder particle velocity
• Additional shield gas protection
• Exchangeable powder nozzle tips
• Powder mixing chamber
• Robust Water Cooling – several hours of continuous operation
Coaxial Cladding Nozzles

![Image of Coaxial Cladding Nozzle with laser beam, powder jet, shield gas, melt pool, and welded track.]
Coaxial Cladding Nozzle

Benefits of using Coaxial Nozzle

– Ability to move in all directions
– High deposition rates
– High powder utilization efficiency
– Continuous operation

Video of coaxial cladding nozzle in use
Custom Nozzles – Cladding 3D Shapes

- Nozzles capable of cladding horizontal and 3D contours
Custom Nozzles - ID Cladding Nozzle

ID head for coating inside tubes and pipes and hard to reach areas
Min tube diameter : 4”   Maximum clad length: 39”
Coating materials: Ni Base, Co Base, Carbides in Ni or Co base
Applications

• Surface property enhancements

• Repair and remanufacturing
Surface Protection Applications – Coatings for Corrosion/Wear

- Rods – 1” to 15” in diameter, 2ft -several ft long
- Cladding for corrosion and wear resistance
- Common materials- CCW, Inconel 625

Cross-section of rod clad with Inconel 625
Surface Protection Applications – Automotive Valves

• Conventional Coatings use PTA

• Laser clad valves have a superior performance vs. PTA:
  – Low heat input & fast cooling => fine microstructure
  – Low dilution
  – High hardness

Cross-section of engine valve laser clad with Stellite 6
Surface Protection/ Repair Applications- Drilling and Mining

• Oil Drilling components require extreme wear resistance
• Substrate: 414X Alloy Steel/17-4 Stainless Steels
• Clad material: 60% WC – Nickel base

Laser Cladding on Drill Stabilizer

Photo Courtesy: Apollo Machine and Welding Ltd

Cross-section of 60-40 WC/Ni clad
Repair Applications – Aerospace

- Repair of Turbine blisks
- Restoration of damage blades
- Laser generated structure of Ti6-2-4-2
- Repair of damaged blades in closed Argon atmosphere
Applications- Mould and Plastic Extrusion

• Potential Hardfacing Applications:
  – Plastic Extrusion Barrels
  – Bearing Housings
  – Flow Restrictors
  – Flow Diverters
  – Corrosion resistance coatings in pipes
  – Valve Housing
  – Localized repair inside tubular components & hard to reach places
ID Cladding Process Video

Laser cladding inside 4” bearing housing with Inconel 625
ID Cladding Applications

Laser hardfacing inside 5” tube with 60% Tungsten – 40% Nickel based matrix

Cross-section of sample ID clad with 60% WC -40 % Ni base matrix
Future Trends – Hybrid Laser Cladding

• Deposition rates can increase by 2X -3X using an Inductive process to preheat the part

Induction assisted laser cladding developed by Fraunhofer CCL/IWS
Future Trends – Superior wear performance

- Wear performance 3-4 X times Tungsten Carbide using diamond particles

Cross-section of diamond clad sample developed by Fraunhofer CCL (Patented)
Thank You!

For Further Information, Please Contact:

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www.ccl-coatings.com
Course #4: Laser Additive Manufacturing
Course Instructors: Aravind Jonnalagadda & Siegfried Scharek

Please rate the following: (circle)

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<thead>
<tr>
<th>Course</th>
<th>Excellent</th>
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<td>Course well paced</td>
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Would you recommend this course to others in your profession? Yes No

What was the strongest feature of the course?
______________________________________________________________________________
______________________________________________________________________________

What was not covered that you felt should have been covered (if anything)?
______________________________________________________________________________
______________________________________________________________________________

What would you like to hear more about next time?
______________________________________________________________________________
______________________________________________________________________________

What was covered that left an impression/impact on you?
______________________________________________________________________________
______________________________________________________________________________

Suggestions & Comments (for this course or courses you would like in the future):
______________________________________________________________________________
______________________________________________________________________________

Name: (optional) ________________________________________________________________

Please return evaluation form to the Registration Desk by Thursday afternoon or fax 407.380.5588 to LIA upon your return home.

THANK YOU!