Thermal history modelling to understand microstructures observed in repair technology of Ti-6Al-4V

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1. Introduction

2. Numerical model

3. Constant Track Length (CTL) results

4. Decrease Track Length (DTL) results

5. Conclusion & Perspectives
Introduction

Innovative technology

Production of dense parts

Multilayer metal deposit

Very high cooling rates (ultrafine grain microstructure)

Bhattacharya & al. (2011)

Sirris

Need of a thermal model:
Study of processing parameters:

- laser power
- powder flow
- preheating temperature (T°)
- laser beam velocity
Interaction Laser - Material

Marion et al. 2015

«MacroClad» & «Decrease Track Length (DTL)» strategy

«MacroClad» & «Constant Track Length (CTL)» strategy
Introduction

Material: Ti-6Al-4V

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<tbody>
<tr>
<td>Composition %mass.</td>
<td>5.5 – 6.5</td>
<td>3.5 – 4.5</td>
<td>0.25</td>
<td>0.08</td>
<td>0.13</td>
<td>0.05</td>
<td>0.012</td>
<td>Bal.</td>
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Solution Treat 1050°C-30 min.

β-Transus=994°C

β → α

β → α’ β → αm

M_s = 575°C

525°C/s

410°C/s

1.5°C/s

20°C/s

Continuous Cooling diagram– Ahmed et al. 1998

Microstructure evolution

Hardness Map– CTL – Paydas et al.

Materials and Design 2015
Experimental data

Geometry of the machined substrate

Path of laser beam (7 tracks/layer)

Deposit cycles with constant track length and time duration (10 Layers)

Laser off

Temperature measured at the thermocouple
Introduction

Experimental data

Microstructure of Constant Track Length
Laser used by Sirris

Top-hat profile of the laser beam energy

Power density concentration

1.4 mm

1.6 mm

At each time step → Updated boundary conditions
Constant Track Length strategy

Temperature (K)
- Red = 3500 K
- Blue = 300 K
Comparison between the simulated and the experimental thermal history from the thermocouple
**Constant Track length strategy**

Fusion zone (FZ) and the heat-affected zone (HAZ)

Depth of Fusion zone

![2D view of thermal field within HAZ](image)

<table>
<thead>
<tr>
<th></th>
<th>Depth</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
<th>Layer 4</th>
<th>Layer 5</th>
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<tbody>
<tr>
<td>Simu</td>
<td>$h_{DL}$ ($\mu$m)</td>
<td>508</td>
<td>688</td>
<td>709</td>
<td>730</td>
<td>793</td>
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<tr>
<td></td>
<td>$h_{HAZ}$ ($\mu$m)</td>
<td>1618</td>
<td>1864</td>
<td>2174</td>
<td>2377</td>
<td>2605</td>
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<tr>
<td></td>
<td>$H_{AZ\beta + HAZ_\alpha + \beta}$</td>
<td>1501</td>
<td></td>
<td></td>
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<tr>
<td>Measured</td>
<td>$h_{DL}$ ($\mu$m)</td>
<td>450</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>$h_{HAZ}$ ($\mu$m)</td>
<td>Not accessible, different zones cannot be recovered</td>
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</tr>
<tr>
<td></td>
<td>$H_{AZ\beta + HAZ_\alpha + \beta}$</td>
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</tbody>
</table>
Constant Track length strategy
Constant Track length strategy

Time-Temperature

Point 1 – Section A

Temperature (K)

Time (s)

Liquid

β

α+β

Ms

TS

M_{S_{Krespo}}

M_{S_{Kelly}}

M_f

Point 1

500

1000

1500

2000

2500

3000

3500

0

100

200

300

400

500

600
Constant Track length strategy

Time-Cooling rate

High $T$ + Low $\dot{T}$ $\rightarrow$ $M_s$
Constant Track length strategy

Point 4 – Section A

Time-Temperature

Temperature (K)

Time (s)

T_s

Liquid

T_β

M_s_Krespo

α+β

M_s_Kelly

M_f

Ms

Constant Track length strategy
Conclusion

Prediction in Section A:
• Identical $T^\circ$ history
• $T_{\text{average}} > Ms$
• $\dot{T}$ at the end low

→ basket-weave Widmanstätten structure

Prediction in Section B:
• $T^\circ$ History of five nodes identical
• Same microstructure
DTL strategy
Decrease Track Length strategy

Temperature (K)
Red = 3500 K
Blue = 300 K
Decrease Track Length strategy

Validation at thermocouple for 10 layers

Temperature (K) vs Time (s)

- Red: Simulation
- Blue: Experiment

Validation at thermocouple for 10 layers
Decrease Track Length strategy

Hardness measurement (Hakan et al. 2015)

α’ martensite
Decrease Track Length strategy

Section A

Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
Point 7

Section B

Decrease Track Length strategy

Point 1 – Section A

Time-Temperature

Temperature (K)

Time (s)

Point 1

Point 1

Temperature (K)

Time (s)

Point 1

Temperature (K)

Time (s)

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Time (s)
Decrease Track Length strategy

Ms → Yes
Ms cannot decompose in alpha

Point 2 – Section A
Decrease Track Length strategy

Point 3 – Section A

Less Ms than point 2

Temperature (K)

Time (s)
Decrease Track Length strategy

Point 4 – Section A

Less Ms than point 2 and 3
Decrease Track Length strategy

Time-Temperature

Point 5 – Section A

Temperature (K)

Time (s)

Liquid

\( T_S \)

\( T_\beta \)

\( \alpha + \beta \)

\( M_{S_{\text{Krespo}}} \)

\( M_{S_{\text{Kelly}}} \)

\( M_s \)

\( M_f \)

Point 5
Decrease Track Length strategy

Time-Temperature

Point 6 – Section B

Temperature (K)

Time (s)

Point 6

Liquid

β

T β

M S_Krespo

M S_Kelly

M s

Ms

Decrease

Track

Length

strategy

α+β

M s

Ms

M f

0

100

200

300

400

500

500

1000

1500

2000

2500

3000

3500

29
Decrease Track Length strategy

Time-Temperature

Point 7 – Section A

Point 7

Temperature (K)

Time (s)

Decrease

Track Length

strategy

Ms

Liquid

β

α+β

Ms_{Krespo}

Ms_{Kelly}

M_f

T_{\beta}

T_S

Ms

A B C D E F G H I J K L M N O P Q R S T U

H_{\nu_o}

375

350

325

300

400
Conclusion & Perspectives

Done

Qualitative prediction // experience
HAZs size within substrate  Melt pool size

Prediction in Constant Track Length:
- Homogeneous $T^\circ$ history
- $T_{\text{average}} > \text{Ms}$
- $\dot{T}$ at the end  low

Prediction in Decrease Track Length:
- Heterogeneous $T^\circ$ history
- At some location :
  $T_{\text{average}} < \text{Ms}$ and $\dot{T}$ high

On going

Fully couple thermo-mechanical-metallurgical analysis, % phase
Thank you for your attention!