Developing Additive Manufacturing Parameters

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Typical requirements & Trade-Offs

- Soot/Weld spatter formation
- Recoating behavior
  - Vertical walls
  - Up/Downsides
- Non machined
- Machined
- As built
  - Post processed
- Exposure time
- Recoating time
- Bulk porosity
  - (Sub)contour porosity

Stability
Density
Typical requirements & Trade-Offs

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Competing requirements need careful optimisation of parameter set
Basic Parameter Development Process

- **Single Vector Investigations**
- **Bulk – DOEs**
- **Bulk – Stability**
- **Heat treatment (HIP)**
- **Contour – DOEs**
- **Volume-/ Lattice Support**

**Output:**
- Melt pool dimensions
- Density
- Productivity
- Mech. properties
- Geometry/ Position dependency
- Recoating behavior
- Post processed mech. properties
- Surface quality
- Fatigue properties
- Frozen parameter set
Single track analysis

**Single tracks – Alloy 718**

- **Width**
- **Depth**

**Bulk / Contour**

**Benefits**

- Melt pool dimensions
- Determine amount of remelting
- Adjustment of offsets for contour and downside
- Detect melt pool shape & irregularities
- Microstructure formation

### Graph

- **Track depth (width) / μm**
  - Speed / mm/s
  - Track depth (width) / μm
  - Speed / mm/s
  - Track depth (width) / μm
  - Speed / mm/s
  - Track depth (width) / μm
  - Speed / mm/s

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**Single Vector Investigations**
Single track + Bulk cross section Analysis

Single tracks:

Connected single tracks:

AlSi10Mg

„Keyhole“

„Lack of fusion“

„Gas porosity“

Line energy (Power/Speed)↑

Density

Bulk – DOEs
Productivity – Effects on build rate

Build rate – AlSi10Mg

**Typical build rates for M2 Dual Laser**

<table>
<thead>
<tr>
<th>Description</th>
<th>Rate (cm³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical melting rate bulk</td>
<td>58.8</td>
</tr>
<tr>
<td>Maximum productivity</td>
<td>51.9</td>
</tr>
<tr>
<td>Typical build rate with recoating</td>
<td>17.2</td>
</tr>
</tbody>
</table>

* layer thickness x scan velocity x hatch distance
** with QM Coating

➢ Strong variation of build rate due to various effects
➢ Standardized build layout is used to determine typical build rate
Productivity & Trade-Offs

Increase productivity:

- Layer thickness $\uparrow$
- Scan speed $\uparrow$
- Hatch distance $\uparrow$

But:
- Lower surface quality
- Less amount remelting/track overlap
- Increased amount of porosity
- Reduced ductility

Spider Plot – AlSi10Mg

- 30$\mu$m
- 40$\mu$m
- 60$\mu$m

Strength
Ductility
Productivity
Density

Surface finish downside
Surface finish vertical
Influence bulk parameter on mechanical properties

Grain size – Ti6-4 (etched samples)

Mechanical Properties – Ti6-4 (heat treated)

Smaller spot size leads to improved mech. properties
Influence bulk parameter on mechanical properties

**Microstructure**

### Ti6-4

- Higher hatch distance leads to smaller and less elongated grains

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**Hatch**

### Residual Stresses

- Higher scan speed leads to higher residual stresses

### Speed

- Lower laser power leads to improved mech. properties

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**Power**

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**Mech. properties**

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Impact of Heat Treatment

Alloy 718

<table>
<thead>
<tr>
<th>Heat Treatment</th>
<th>As-Built</th>
<th>SR</th>
<th>SR+HIP</th>
<th>SR+HIP+ Solution</th>
<th>SR+HIP+ Solution &amp; Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>XY</td>
<td>XY</td>
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</table>

**Stress Relief**
- Reduce internal residual stress
- Allows for removal from platform with minimum distortion

**HIP**
- Reduce internal porosity
- Initiates recrystallization
- Transforms microstructure

**Solution**
- Homogenizes structure
- Sets grain size after quench
- ↓ strength
- ↑ ductility

**Age**
- Precipitation of strengthening phases
- Stabilizes structure
- Best balance of properties
Influence of heat treatment on mechanical properties

Phase Diagramm - AlSi10Mg

Mechanical properties

- **T6 (SHT+aging)**
  - Minimize anisotropy
  - Stress relieve
  - Ductility optimized

- **Stress relieve**
- **Strength optimized**

➢ Heat treatment can be optimized to adjust desired balance between strength & ductility
Fatigue Behavior DMLM vs Wrought

Alloy 718

- Bulk fatigue life approaches wrought capability
- Strong influence of surface quality on fatigue life
Contour porosity & roughness – Vertical walls

Line energy (Power/Speed) ↑

"Powder adherence“  "Optimum“  "Keyhole“

"Subcontour porosity“

Vertical walls: Conflict between contour porosity & surface roughness

MS300:

Contour porosity

Roughness Ra / µm

Contour porosity

No
Medium
High

Optimum
Contour porosity & roughness – Downsides

Downside 45°

MS300

Vertical walls

"Optimum"

Often inverse behavior for vertical walls & downsides

Surface quality

Contour – DOEs

Line energy (Power/Speed)↑

Small spot

Large spot

Roughness Ra / µm

Optimum

Roughness Ra / µm

Power / W

Speed / mm/s

Power / W

Speed / mm/s

Roughness Ra / µm

Roughness Ra / µm

Roughness Ra / µm
Features of new segmentation method

Thin wall segmentation

- Separate thin wall exposure
- Independent downside exposure
- Definition of minimal vector length
- Definition exclusion angle

Downside segmentation

Bulk

Adv. Surface Contour

Adv. Surface Area

Downside Element Contour

Downside Surface Area

Benefits

- Separate thin wall exposure
- Independent downside exposure
- Definition of minimal vector length
- Definition exclusion angle
Summary

- Optimum balance between several (often conflicting) properties has to be found
- Slight modifications of the parameter can have huge impact on multiple attributes

Broad Know-how necessary, not only about the:
- DMLM Process
- but also on:
  - Microstructure & mechanical properties
  - Post processing
  - Design & Application
  - Powders
Imagination at work