Additive Powders: The Relationship between Powder, Process and Properties

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Agenda:

- Powders for Additive – more than PSD & chemistry
- Powder characterization @ GE Additive
- GE Additive Powder Specifications
- Relationships of Powder-Process-Properties
- Relationships Powder Production-Powder Properties
- Powder vendor qualification process @ GE Additive
- Conclusion
Powders for Additive
Product PSD

Different processes need different PSD

For DMLM different PSD are available for different machines/built parameters: 15-45, 15-53, 20-63 microns
Selecting the right PSD because it influences:

**Price** because of powder production yield

**Flow properties** because of fine powder content

** Reactivity** because of surface area

**Oxygen content** because of surface area

**Process parameters** because of energy density/build rate

**Part design** because of layer thickness, surface finish, feature resolution, etc...

Global decision to be taken early in the design stage with strong cost, design and EHS influences

<table>
<thead>
<tr>
<th>Particle Size (µm)</th>
<th>Oxygen Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45-106</td>
<td>0.07%</td>
</tr>
<tr>
<td>15-45</td>
<td>0.10%</td>
</tr>
<tr>
<td>0-20</td>
<td>0.17%</td>
</tr>
</tbody>
</table>

**Ti-6Al-4V (with same raw material)**
Metal powders for Additive more than PSD & chemistry

Two 316L powder samples:

- Typical chemical composition
- Similar particle size distribution (PSD)

→ First impression suggests similar behavior/ results
Metal powders for Additive more than PSD & chemistry

But:

- Different atomization processes
- Different morphology
→ Different behavior!!
→ Different results!!

For selection/specification of Additive powders more than PSD & chemistry is required!
Powder characterization @ GE Additive
Powder characterization @ GE Additive

**Powder properties**
- PSD – laser diffraction / sieving/ image analysis (dynamic or static)
- Chemistry – RFA / ICP / HGE / CA/ EDS
- Shape – Malvern Morphology/ SEM

**Powder condition**
- Moisture content - Aquatrac
- Contamination – CT/EDS
- Surface chemistry – SEM/EDS
- Charge - GranuCharge

**Fundamental research**

**Powder lab**
- AP&C
- ATC
- CL
- GRC

**Certified lab**

**Powder behavior**
- Rheology – FT4
- Flow – Hall/Carney Flow / GranuDrumm
- Packing – Apparent/ Tap density
- Spreading – test rigs

FT4/GranuDrumm?
GE Additive Powder Specifications
GE Additive Powder Specifications

Structure:
1. Scope and Background – provide consistency
2. Applicable Documents – referred standards/specs
3. Requirements – PSD&chemistry + more!
4. Testing and Verification – definition of test conditions/ methods
5. Packing and Shipping – provide consistency
6. Related Information and Notes
GE Additive Powder Specifications

Additional requirements (besides PSD&chemistry):

- Specification of powder manufacturing (melting, atomization, post processing)
- Raw material
- Powder properties: apparent/tap/true density, flow rate
GE Additive Powder Specifications

Aims:

✓ Provide consistency across different products
✓ Provide comparable results
✓ Ensure consistent of powder
✓ Minimize risk of contamination
Relationships of Powder-Process-Properties
Relationships of Powder-Process-Properties Interaction PSD/shape-Process window

**Evolution of AlSi10Mg**

- Remove of fines < 10 µm
- More spherical shape of particles
- More consistent particle shape
  - Better flow & lower oxygen content
  - More consistent spreading/packing

![CL31](image1.png) ➔ ![GE Additive AlSi10Mg](image2.png)
Relationships of Powder-Process-Properties Interaction PSD/shape-Process window

Impact on Process:

• No fines – lower EHS risk, more easy powder handling/removal/cleaning
• Better flow enables use in machines like Xline
• Change in PSD and shape results in change in process window
Relationships of Powder-Process-Properties Interaction PSD/shape-Process window

Impact on Process/Properties:

- Enabling finer microstructure
- Enabling use of hard recoater
- Enabling higher productivity
- Minimizing recoating defects

CL31

GE Additive AlSi10Mg
Relationships of Powder-Process-Properties
Fines (particles < 10 µm)

Two powder samples:
• Same material
• Similar shape
• Similar D50

**But:** different amount of fines (<10 µm)

<table>
<thead>
<tr>
<th></th>
<th>Sample 1</th>
<th>Sample 2</th>
</tr>
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<tbody>
<tr>
<td>D50</td>
<td>26 µm</td>
<td>27 µm</td>
</tr>
<tr>
<td>&lt;10 µm</td>
<td>10 %</td>
<td>0%</td>
</tr>
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Relationships of Powder-Process-Properties
Fines (particles < 10 µm)

Impact on Process: → different porosity levels

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Sample 1

Sample 2
Relationships of Powder-Process-Properties

Fines (particles < 10 µm)

Additional powder characterization:

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Flow rate (50g)</td>
<td>24 s</td>
<td>14 s</td>
</tr>
<tr>
<td>Apparent density (g/cm³)</td>
<td>4.44</td>
<td>4.45</td>
</tr>
<tr>
<td>Tap density (g/cm³)</td>
<td>5.28</td>
<td>5.08</td>
</tr>
</tbody>
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<tr>
<td>&lt;10 µm (wt %)</td>
<td>10 %</td>
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Different amount of fines results in different behavior regarding flow and packing of the powders!
Relationships of Powder-Process-Properties

Fines (particles $< 10 \mu m$)

Potential root cause:

- Different energy input due to differences in laser absorption
- Different flow and packing resulting in different layer formation
- Different layer formation causes differences regarding interacting powder volume

➢ In some cases fines are mandatory to achieve optimal results!
Relationships Powder Production - Powder Properties
Relationships Powder Production - Powder Properties

**Feedstock**
- chemical composition

**Atomization medium**
- impurities
- particle shape
- PSD

**Melting**
- chemical composition
- impurities

**Design of atomizer/nozzle**
- particle shape
- PSD
- satellites
- agglomerates
Advanced Plasma Atomization - APA™

- Better feeding control
- Pre-alloyed wire
- Ceramic free melting
- High purity spherical powder, with high flowability and low porosity
- Higher yield of fine particles

Hybrid technology – Quality of PREP with the high yield in fines of GA
Dynamic Behavior
Optimizing Morphology & Density

Atomizing with cold gas:
- Melt is quenched
- Entrapped gas pockets

Atomizing with hot gas:
- Longer residence time
- Argon is allowed to escape
- Minimize impact of collisions at atomization point

Continuous atomization:
- Lowers particle interaction
Relationships Powder Production - Powder Properties
Lowering Internal Porosity Level

2D Metallography with SEM

APA™
Gas Atomized

Pycnometry and CT-Scan

Porosities act as stress concentration and fatigue failure initiation sites
Advantages of APA™ process

➢ High batch to batch consistency
➢ High sphericity
➢ Low content of satellites
➢ Lower reactivity
➢ Very low internal porosity
➢ Enhanced flow properties
➢ Improved packing behavior

Ti-6Al-4V 45-106 µm
Powder vendor qualification process @ GE Additive
Powder vendor qualification process @ GE Additive

- Is quality system in place?
- Risk assessment!
- Capability/stability to supply constant quality even for large scale production and for long term?
- Performance of parts build with the powder on CL machines?
- Powder characterization!

Ensuring best and consistent powder quality for our customers!
Conclusion
Conclusion

- Powders for Additive are more than only PSD and chemistry
- In house capability for full characterization
- Enhanced specifications ensure consistent part properties
- Fines have huge impact on process, but optimal amount depending on material/application
- APA™ powders show outstanding properties regarding shape, flow and internal porosity
- Powder vendor qualification process in place
Imagination at work