VTT 3DMetalprint

Joni Reijonen, VTT

3D-vallankumouspäivä
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Vossi Group, Tampere
Opportunities in the world of huge challenges
Experimental facilities

From powder to product – agile pilots

Material & component testing
Post processing
Direct Write Technology
Selective Laser Melting
Powder characterization
Plasma spheroidization
Gas atomization

Application Services
Competitive products & new business models

Design for AM
Digital spare parts
Added intelligence & functionality

Production Services
Increased productivity & quality

Thermal distortions mitigation
Post-processing
Integration of AM into production

Material Services
Increased quality & material performance

Powder printability
Application driven materials
Virtual material factory
Application services
Hydraulic valve block

66 % lighter
no leaks
optimized flow
"When we saw hydraulic block by VTT we understood it is feasible and sensible”

Valeria Tirelli, CEO at AIDRO Hydraulics & 3D printing
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design outside the box
Identifying 3D-printable spare parts: case

Top-down approach
Which of these parts can be printed?

Step 1: Scope and selection criteria determination
Step 2: Technologically possible spare parts
Step 3: Technologically feasible spare parts
Step 4: Technologically and economically feasible spare parts

Company A
- 198,638 parts
- 25.8%
- 5.9%
- 2.1%

Company B
- 17,182 parts
- 21.8%
- 5.5%
- N/A
Digital spare parts – Demonstrations

1:1 replacement part: heat plate

Repairable spare part: valve seat ring
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from cloud to user: digital spare parts
Smart shaft
Smart shaft informs about using condition

Successful Proof-of-concept of 3D printed smart shaft, which has acceleration sensor embedded inside the structure.

- Sensor and wiring embedded in 3D printed component during the manufacturing
- Wireless data transfer from the component to cloud
- Approach can be utilized in different components - sensors (e.g. thermocouples, Acoustic Emission sensor)
- Potential benefits:
  - More accurate in situ measurements
  - Sensing solution well shielded against harsh environment
  - Applications e.g in Condition Based Monitoring, tracking, digital ID, in various industrial domains
Smart shaft:
Embedded sensors inside AISI 316L component for improved condition based monitoring.
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embedding intelligence to machinery
Production services
VTT Pipe
Mitigation of thermal distortions

Distortions due to damaged recoater

Successful print – effective thermal conduction at collar support
Process monitoring: thermal imaging

a) Studied cross-sections in CAD model.

b) The monitored temperature distributions at the end of melting of the layers.

Design by VTT 2015

Kimmo Ruusuvuori, VTT 2015
Geometrical accuracy

No component level distortion, all deviations are covered in machining allowances.

ISO 10360-2 accuracy $MPEe = (0.35 + L/1000) \mu m$, $L = m$

Measurement range $X=910 mm, Y=1010 mm, Z=610 mm$

FARO analysis by Antti Vaajoki, VTT
VTT → Knowledge sharing → Impact

VTT Pipe case study

Background
A mock-up SLM test component was designed at VTT for assessment of printability and geometric accuracy both before and after machining. Design principles and objectives included:

- Features available for SLM, e.g. self-supporting elliptic cross-section for horizontal pipe, rivet and local details to modify overhanging members to be self-supporting
- Inclusion of features challenging to manufacture by SLM that are common in industrial components, e.g. thick features and overhangs
- Smooth transitions used at corners for good fatigue strength
- Only functional surfaces are designed to be machined
- Bolt holes are reamed using pre-fabricated holes
- Dimensions limited so component can be produced in SLM125HL chamber

https://www.vttresearch.com/vtt-pipe-case-study

Presentations in:
NAFEMS Nordic Seminar: Exploring the design freedom of additive manufacturing through simulation. 10-11.12.2018, Helsinki
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VTT Pipe – open source AM test component
Automating post-processing for AM
Digital manufacturing chain (MBD)

- 3D MBD CAD model
- 3D CAD model
- 2D manuf. drawing

**Print**
- (Heat treatment)
- Remove from platform
- (Remove supports)

**Inspect**
- Automatic toolpath generation
- Manual
- FARO configuration (fast)
- Manual

**Machining**
- Manual
- CNC programming
- Manual

**Final inspect**
- Manual
- CMM programming

Post-processing time and cost can be more than printing cost
Can we automate some of the post-processing setup with MBD?
Machining (CNC)

- MBD in machining strategy generation
  - Can aid in the creation of the tooling paths
  - All the dimensioning included in the model
  - If a certain dimensioning is missing this can be checked directly from the model. Efficiency e.g. in comparison to traditional 2D paper drawings

- Tested Mastercam 2018-> reads MBD annotations (step 242)
  - Still just feature based machining

- Solidworks CAM 2018 (no license yet)
  - “Tolerance based machining from MBD tolerance and surface finish information”
Final inspection (CMM)

- CMM Mitutoyo Legex
- Manual programming 1-2 days
- Using Micat Planner software to automatically create toolpath from MBD annotations
- Work reduced by 70 % from days to hours

- At this moment works only for few CAD formats
- Automatically generated CMM script is more difficult to edit afterwards than traditional recorded (teach mode) script
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*automated post-processing for AM*
Material services
Additive manufacturing of soft magnetic materials
Topology optimization of switched reluctance machines

- Globally Convergent Method of Moving Asymptotes (GCMMA) optimization algorithm on COMSOL Multiphysics
- TO objective: minimize torque ripple by optimizing torque profile
- The target value for the torque, 0.16 Nm, was achieved quite well, except for the last rotor angle, when the stator and rotor teeth are aligned.

\[
\text{minimize } f(\psi) = \sum_{j=1}^{n} (T_j - T_k)^2
\]
Powder preparation

- Fe-Co alloys were gas atomized, sieved, air classified and the resulting powder characterized to determine suitability for SLM (flowability, size, shape, packing)
Printing parameter optimization

Creating the experimental designs
Using D-optimal design of experiments

- Hatch width (µm) vs. Scanning speed (mm/s)
  - VED 50
  - VED 100

Printing samples and measuring density using image analysis

Fitting a numerical model and calculating the optimal parameters

- Power (W) vs. Scanning speed (mm/s)
  - VED 50
  - VED 100
Printing of test specimens

- Test parts were produced for magnetic and mechanical testing
# Magnetic properties

- Good magnetic properties $B_r$, $H_c$ and $\mu_{\text{max}}$ reached.
- Eddy current losses still high, next development steps to reduce the losses

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Heat treatment</th>
<th>$B_r$ (T)</th>
<th>$H_cB$ (A/m)</th>
<th>$H_cJ$ (A/m)</th>
<th>$\mu_{\text{max}}$</th>
<th>$H(\mu_{\text{max}})$ (A/m)</th>
<th>$H_{\text{max}}$ (kA/m)</th>
<th>$J_{\text{max}}$ (T)</th>
<th>$B_{\text{max}}$ (T)</th>
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<tbody>
<tr>
<td>Bar</td>
<td>As-built</td>
<td>0.90</td>
<td>1344</td>
<td>1345</td>
<td>307</td>
<td>1930</td>
<td>55</td>
<td>2.10</td>
<td>2.17</td>
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<tr>
<td>Ring</td>
<td>As-built</td>
<td>0.88</td>
<td>1287</td>
<td>1288</td>
<td>322</td>
<td>1754</td>
<td>9</td>
<td>1.56</td>
<td>1.57</td>
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<tr>
<td>Bar</td>
<td>HT1</td>
<td>1.59</td>
<td>73</td>
<td>73</td>
<td>9156</td>
<td>72</td>
<td>56</td>
<td>2.22</td>
<td>2.29</td>
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<tr>
<td>Ring</td>
<td>HT1</td>
<td>1.56</td>
<td>493</td>
<td>493</td>
<td>1922</td>
<td>125</td>
<td>9</td>
<td>2.16</td>
<td>2.18</td>
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<tr>
<td>Bar</td>
<td>HT2</td>
<td>1.51</td>
<td>52</td>
<td>52</td>
<td>17000</td>
<td>47</td>
<td>56</td>
<td>2.21</td>
<td>2.28</td>
</tr>
<tr>
<td>Ring</td>
<td>HT2</td>
<td>1.31</td>
<td>47</td>
<td>47</td>
<td>13000</td>
<td>60</td>
<td>9</td>
<td>2.22</td>
<td>2.23</td>
</tr>
<tr>
<td>Commercial bar*</td>
<td>HT1</td>
<td>0.51</td>
<td>59</td>
<td>59</td>
<td>4300</td>
<td>272</td>
<td>57</td>
<td>2.16</td>
<td>2.24</td>
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<tr>
<td>Commercial ring*</td>
<td>HT1</td>
<td>1.26</td>
<td>40</td>
<td>40</td>
<td>12000</td>
<td>53</td>
<td>10</td>
<td>2.22</td>
<td>2.23</td>
</tr>
</tbody>
</table>

Note: $\mu_{\text{max}}$ reached for $B_r$, $H_c$, and $\mu_{\text{max}}$. Eddy current losses are still high, and the next development steps are to reduce these losses.
Microstructure & mechanical properties

- Mechanical properties of printed Fe-Co-V samples compared well with standard FeCo-alloy

<table>
<thead>
<tr>
<th>Material</th>
<th>Build orientation</th>
<th>Condition</th>
<th>R_y0.2 (MPa)</th>
<th>R_m (MPa)</th>
<th>A (%)</th>
<th>E (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe-Co-V</td>
<td>Horizontal</td>
<td>As-built</td>
<td>839</td>
<td>968</td>
<td>4</td>
<td>230</td>
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<tr>
<td></td>
<td></td>
<td>HT1</td>
<td>303</td>
<td>363</td>
<td>3</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HT2</td>
<td>266</td>
<td>306</td>
<td>3</td>
<td>210</td>
</tr>
<tr>
<td>ASTM A801-09 alloy 1</td>
<td></td>
<td>Heat treated*</td>
<td>250</td>
<td>350</td>
<td>3</td>
<td>215</td>
</tr>
</tbody>
</table>
Component manufacturing & testing

- Optimized rotor for electrical machine was manufactured
- The results that we have obtained are promising, i.e. the key characteristics mainly fulfil the requirements of commercial electrical machines
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from powder to product
### AMable Open Call
**Your Opportunity**

1. Do you have an innovative idea for a functional product that needs AM to become alive? You can tell & sell its story publicly but you cannot achieve the implementation yourself?

2. You can get support from European Additive Manufacturing Competence Centers – teamed up in AMable – through services for design, testing, simulation, scale up, etc.

3. You can get funding for your development activities if you are an SME in the supplier role, eligible under Horizon2020 rules and if there is a SME or mid-cap in the user role.
Thank you!

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www.vttresearch.com/3d-printing