NDT Challenges and Solutions for Metal Additive Manufactured (AM) Parts & Structures

Space Tech Expo
Bremen, Germany, 24-26 October 2017
Everything starts with the Process Map
Process Chain - AM

1. 3D-Model, Drawing and Bill of Materials
2. Job Preparation in Software
3. 3D-Printing (SLM)
4. Stress Relief Heat Treatment
5. EDM Wire Cutting
6. Support Removal
7. Sand Blasting
8. Hot Isostatic Pressing
9. Non-destructive testing (µCT)
10. Machining / Polishing
11. Pickling / Penetrant Testing
12. Final Inspection / Marking / Packing

Source: Airbus/BDLI
Process Chain – AM – Quality/NDT

1. • 3D-Model, Drawing and Bill of Materials

2. • Job Preparation in Software

3. • 3D-Printing (SLM)

4. • Stress Relief Heat Treatment

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6. • Support Removal

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Source: Airbus/BDLI
NDT Simulation

1. 3D-Model, Drawing and Bill of Materials
RT / CT-Simulation

Need for RT/CT-Simulation solution to analyze the inspectability during the design process.

Analysis of CAD models and components for synthetic data

Definition of CT-simulation environment and parameters

CAD designed AM components and results, inspectability

modeling & CT-simulation
Powder Quality

- 3D-Printing (SLM)
Powder Quality

Source:
Airbus Spec: AIPS 01-04-020
Additive Manufacturing – Powder Bed Fusion
Powder Quality analysis & cleaning

- Powder Quality check on-the-fly
- Automated and fast determination of powder properties (form, humidity, contamination, etc.)
- Supervision of the powder quality during the printing process to enable the interruption of the printing in case of contamination
- Automated cleaning in case of contamination
- Quality check and cleaning of the powder in case of re-usage of powder to save costs
Non-Destructive-Testing (NDT)

- Non destructive testing (µCT)
## Defect Catalogue

### Defect catalogues for LB and EB Powder Bed Fusion

<table>
<thead>
<tr>
<th>Defect type</th>
<th>Location</th>
<th>Description</th>
<th>Visual</th>
<th>FPI</th>
<th>X-Ray</th>
<th>CT Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>External defects / distortion</td>
<td>External</td>
<td><img src="image" alt="Image" /></td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Surface porosity, roughness, texture</td>
<td>External</td>
<td><img src="image" alt="Image" /></td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Internal porosity</td>
<td>Internal</td>
<td><img src="image" alt="Image" /></td>
<td>✔️</td>
<td></td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Inclusion (foreign material)</td>
<td>Internal / External</td>
<td><img src="image" alt="Image" /></td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Lack of fusion (unmolten layers)</td>
<td>Internal/external</td>
<td><img src="image" alt="Image" /></td>
<td>✔️</td>
<td>✔️</td>
<td>No (1)</td>
<td>No (2)</td>
</tr>
</tbody>
</table>

(1): To capture the “Lack of fusion” defect is Hot Isostatic Pressure (HIP) required which eliminates this internal failure with the view on Ti6Al4V. To avoid HIP we need to guaranty that no internal lack of fusion is there. A solution could be a detailed process monitoring (on-line process monitoring).

Source: Airbus
Acceptance Levels

3.2 Acceptance Level

The acceptance levels are divided into A, B and C.

Their differences are based on different external and internal quality levels.

Depending on the classification each part will fall into one of the three grades.

Thus, the acceptable quality level of grade A, which depends on the production procedure and the type of material, represents the best production results which can generally be reached under optimum conditions. The acceptable quality levels of grade B and grade C correspond to greater tolerances.

Note: Acceptance levels shall be given on the drawing.

<table>
<thead>
<tr>
<th>Classification of parts (AM2396.3)</th>
<th>AIMS</th>
<th>Acceptance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QL1</td>
<td>A</td>
</tr>
<tr>
<td>2.1</td>
<td>QL1</td>
<td>A</td>
</tr>
<tr>
<td>2.2</td>
<td>QL1</td>
<td>B</td>
</tr>
<tr>
<td>2.3</td>
<td>QL2</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>QL3</td>
<td>C</td>
</tr>
</tbody>
</table>

Source:
Airbus Spec: AIPS 01-04-020
Additive Manufacturing – Powder Bed Fusion
## Application of NDT

8.2 Part

All manufactured parts shall be inspected in accordance with Table 7. Specific requirements mentioned on the drawing need to be considered, too.

### Table 7: Inspection Methods and Test Frequency

<table>
<thead>
<tr>
<th>Acceptance level</th>
<th>Inspection Method</th>
<th>Frequency (Parts per batch)</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(digital) X-ray or CT &lt;sup&gt;a&lt;/sup&gt;</td>
<td>100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td>See Annex A</td>
</tr>
<tr>
<td></td>
<td>Penetrant</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(digital) X-ray or CT &lt;sup&gt;a&lt;/sup&gt;</td>
<td>20% / 100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Penetrant</td>
<td>100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>(digital) X-ray or CT &lt;sup&gt;a&lt;/sup&gt;</td>
<td>100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td>See Annex A</td>
</tr>
<tr>
<td></td>
<td>Penetrant</td>
<td>100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>(digital) X-ray or CT &lt;sup&gt;a&lt;/sup&gt;</td>
<td>100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td>See Annex A</td>
</tr>
<tr>
<td></td>
<td>Penetrant</td>
<td>30% / 100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Technique used shall be same as used for validation of APS.

<sup>b</sup> The frequency of inspection may be progressively reduced after the additive manufacturing process is established, and extensive statistics are available. This modification shall be validated by the Airbus Quality department.

**Source:**

Airbus Spec: AIPS 01-04-020

Additive Manufacturing – Powder Bed Fusion
Defects to be detected

Failure Requirements stated in the AIMS and the AIPS:

Source: Airbus Spec: AIPS 01-04-020 „Additive Manufacturing – Powder Bed Fusion“

Great challenge for surface treatment
Internal Defects – Digital X-Ray

- Non destructive testing (µCT)
X-Ray Non-Film / Digital X-Ray

Source: GE Inspection Technologies – Industrial Radiography
Internal Defects – Computer Tomography (CT)

- Non destructive testing (µCT)
Different CT-Methods

**Conventional-CT**
- X-ray source
- Examination object
- Detector (flat panel detector)
- Fan beam

**Helix-CT**
- X-ray source
- Examination object
- Detector (flat panel detector)
- Fan beam

**Translational Laminography**
- X-ray source
- Examination object
- Direction of movement
- Detector (flat panel detector)

**Rotational-CT**
- Rotating X-ray source
- Contra rotating Detector
- Object in focal plane
- Object outside focal plane

Testia GmbH
Overview of „sample“ sizes

Micro Scale
~ 20 mm

Macro Scale
~200 mm

Macro+ Scale
> 5000 mm
One CT-Measurement and three Analyses

260 mm

Porosity

Wall-Thickness

Geometric Deviation
AM-Part Inspection

Pore/Defect analysis

2D evaluation
AM-Part Inspection

⚠️ Crack analysis

~150 mm
Powder Residues

Foreign Particle Inspection

~150 mm
Geometrical Analysis

Online/Offline assessment:
- Thickness
- Shape
- Dimensions

Reverse Engineering
# Used CT-Systems in Testia

<table>
<thead>
<tr>
<th>X-Ray Source</th>
<th>Max. power</th>
<th>Detector</th>
<th>Max. object weight</th>
<th>Max. Resolution</th>
<th>Object size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testia CT Micro Focus (Ottobrunn)</td>
<td>225 kV</td>
<td>X-RAY WorX XWT-300-CT 300 kV</td>
<td>225 kV</td>
<td>PerkinElmer Varian 4343</td>
<td>150 kg</td>
</tr>
<tr>
<td>TESTIA CT System (Ottobrunn)</td>
<td>150 W</td>
<td></td>
<td>150 W</td>
<td>PerkinElmer 40x40 cm, 200 µm</td>
<td>~ 3 µm</td>
</tr>
<tr>
<td>Micro Focus CT / Laminography*</td>
<td>600 kV</td>
<td>PerkinElmer 40x40 cm, 200 µm</td>
<td>50 kg</td>
<td>~ 5 µm</td>
<td>Small, medium and large sized components up to Ø 500 mm, h 1000 mm (with range extension)</td>
</tr>
<tr>
<td>Macro-CT*</td>
<td>120 kV/225 kV</td>
<td>PerkinElmer 40x40 cm, 200 µm</td>
<td>150 kg</td>
<td>~ 110 µm</td>
<td>Standard CT</td>
</tr>
<tr>
<td>Mini Focus Robotic RT (Dragonfly)*</td>
<td>90 kW (pulsed)/1,5 kW</td>
<td>Fraunhofer XEye 40x20 cm, 100-350 µm</td>
<td>100 kg</td>
<td>~ 150 µm</td>
<td>High density objects (RT/CT)</td>
</tr>
<tr>
<td>High Energy CT*</td>
<td>---</td>
<td>Row Detector 4000 cm 400 µm</td>
<td>10 000 kg</td>
<td>~ 200 µm</td>
<td>Large and high density objects (RT/CT)</td>
</tr>
</tbody>
</table>

*In cooperation with Fraunhofer EZRT*
External Defects –
Penetrant Testing (PT)

- Non destructive testing ($\mu$CT)
Penetrant Testing (PT)

⚠️ Standard method for castings
⚠️ Currently mandatory acc. to Airbus requirements
⚠️ Surface roughness biggest challenge

Electro polished AM-specimen

AM-specimen before electro polishing
Automisation

• Non destructive testing (µCT)
Fully automated systems possible

- PT Systems
- X-Ray Turn-Key Solutions
- CT Turn-Key Solutions
Testing
Mechanical, Physical, Chemical, etc
Beside NDT, Destructive Testing (DT) is necessary

Typical tests:
- Tensile tests
- Compression tests
- Shear tests
- Metallography
- Hardness tests
- Fatigue tests
- Fracture toughness tests
- …
Online Monitoring End-to-End
Merge NDT and AM Process data

- Integral view of data
- Reducing duplication of work & cost
- Information about correlation between connected data
- Better check for origin of effect and influence to data
- Optimization of process steps by using connected database

NDT Data
NDT Department generates test data of finished parts.

Production Data
Sensor Systems monitor production quality and record every defect.

Connected Data Analytics
„Chain Apps“ collect and analyze data of production and may relate it to NDT data.

*In cooperation with InFactory
Other relevant topics
Live NDT monitoring of printing process

- Check Laser Power
- Check of Accuracy of multiples lasers systems
- Assessment of fusion quality during process
- Calibrated system for melting temperature monitoring

- OT is able to resolve diameters down to 0.2 mm (sure)
- Sizes down to 0.05 mm could be measured with image enhancement and some image processing

*In cooperation with Carl Messtechnik
Products

⚠️ Development of automated inspections systems (RT, PT) on-demand

⚠️ CT-systems Analysis Software (acc. to AITM6-7006)

⚠️ Manufacturing of **Reference Standards** for RT and CT, also **Image Quality Indicator (IQI)**

- Ceramic Ball and Ball-bar for CT Systems signal-to-noise and picture sharpness calibration

- IQI for CT systems
Conclusion
AM relevant fields

Ongoing Developments
- Online quality check of metal powder
- Live NDT monitoring of printing process
- Compilation of NDT and AM Process data

- Automated Inspection systems e.g. for PT, RT or CT
- Reference Standards
- Image Quality Indicator (IQI)
- CT-System Analysis Software

Inspection & Feasibility
- Computed Tomography (CT)
- Radiography (Non-Film) (RT)
- Penetrant Testing (PT)
- Geometry Measurement (Online/Offline)
- Process Monitoring (Shape-Check)

- Tensile tests
- Compression tests
- Shear tests
- Metallography
- Hardness tests
- Fatigue tests
- Fracture toughness tests
- And more…

- X-Ray (Film / Non-Film)
- All NDT Methods (EN4179, NAS-410)
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