Advanced X-ray Computed Tomography in Additive Manufacturing

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Abstract: Additive manufacturing is increasingly used for producing high performance parts, such as turbine blades, medical implants and tools, and therefore quality control is essentially. Hereby X-ray computed tomography (CT) adds value at different stages of the whole process chain as it offers non-destructive testing at high precision. For instance, prior to manufacturing, powder for metal printing is analyzed in terms of size distribution, sphericity, foreign particles and porosity inside the grains. Furthermore, manufactured samples and components are controlled by three-dimensional (3D) failure analysis and dimensional measuring. An iterative process of X-ray CT control and printing parameter changes help optimizing the final product. Later in the manufacturing process, powder residues in the interior structures are easily detected as well. The X-ray CT is also used to regularly verify the system performance of 3D printing machines.

2. Materials and Methods

In this study we’ll present 3 different Titanium samples in the range of μm to dm. Highly sophisticated X-ray CT scanners were used to generate 3D data that were further analyzed with respect to geometry, foreign particles and porosity. This yields in the case of an aerospace bracket to an optimization of the build process with enhanced geometric features and significantly reduced porosity.

3. Results and Conclusion

In summary, there is an increasing tendency for Additive Manufacturing for larger series as well as for critical products which requires new quality control methods in the whole productive chain. Therefore, high precision and non-destructive techniques like X-ray CT are in growing demand. In this contribution we could show several case studies highlighting the power of various X-ray CT analytics.

4. Acknowledgements

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- Materialise NV, Belgium
- University of Paderborn – DMRC, Germany
Introduction / CT Principles

Added Values of CT in Additive Manufacturing

Example CT Results on AM Workpieces

Conclusion
The Waygate Technologies X-ray Product Range

Films
• Complete range of Agfa X-ray films
• State-of-the-art processing equipment
• Film scanning

Digital Imaging
• Computed radiography
• Reusable phosphor plates
• Digital Detector Arrays
• Image processing and storage software

X-ray Sources
• Portable and mobile X-ray systems
• Stationary systems
• Micro- and nanofocus x-ray

2D Systems
• Stationary manual and automated digital X-ray inspection systems
• Fully automated defect recognition software

3D Industrial CT
• 3D failure analysis and process control
• 3D CT for R&D

3D Metrology
• Reproducible 3D coordinate measurement with X-ray CT
• Fully automated CT data acquisition and volume processing

Electronics Inspection
• micro- and nano-focus X-ray
• 2D Software for high resolution electronics inspection
Principle of CT: Reconstruction Method - Spark Plug

Acquisition of 600 projections

600 back projections

3D visualization
CT Principles: critical parameter voxel resolution

Inspection on four different length scales, e.g. casting part

**Complete casting:**
1) 150 µm voxel size, microfocus: macro-porosities, metrology
2) 30 µm voxel size, microfocus: micro-porosities

**Subsection of casting:**
3) 3 µm voxel size, microfocus tube: detailed analysis of micro-pores
4) 0.5 µm voxel size, nanofocus tube, high resolution 3D materialography
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Additive Manufacturing - where and how CT can add value

3D printing machine manufacturers:
- verify system performance, merge with in-situ monitoring

printing powder manufacturers:
- check powder grain sphericity & size, distribution, porosity inside the grains, foreign particle contamination

3D print service companies/users:
- conduct rapid prototyping and QA (failure analysis, dimensional measuring and pre-machining test) of printed workpieces

Standardization organizations:
- perform CT measurements to help defining guidelines in volumetric inspection, complementing to standard NDT techniques for surface and below surface inspection
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Additive Manufacturing – example for CT analysis

Workpiece #1: Aerospace bracket
Material: Titan
Dim (L x W x H): 42 x 42 x 48 mm
Used μCT system: vtomex m 300
inspection Tasks:
defect analysis: porosities, inclusions
dimensional analysis: CAD comparison
19 µm voxel size
Additive Manufacturing – example for CT analysis

CT results: CT vs CAD comparison – void accumulations
Simulation confirms/explains the dimensional deviation found in CT, simulation indicates the area where the main distortion is expected to take place.
Simulation confirms/explains the dimensional deviation found in CT, simulation indicates the area where the main distortion is expected to take place.
Additive Manufacturing – example for CT analysis

Build Orientation and Support generation optimization

- Combination of simulations and engineering experience
- Remove Periodicity
- Avoid (simultaneous) merging of large portions
Additive Manufacturing – example for CT analysis

Dimensional Analysis: comparison with CAD data

Before Printing Optimization

Simulation A

CT scan A

After Printing Optimization

Simulation B

CT scan B
Additive Manufacturing – example for CT analysis

Porosity Analysis A

19 µm voxel size

ROI scan
7.6 µm voxel size
Additive Manufacturing – example for CT analysis

• Reduced porosity (by 33 %), but not removed completely
• Distribution of pores shifted to smaller sizes (positive effect on fatigue lifetime)
• Study to be continued
Workpiece #2: Reaction wheel bracket (ESA)

Material: AlSi10Mg Ceramic

Dimensions (L x W x H): 400 x 220 x 250 mm

Inspection Tasks:
- defect analysis: porosities, inclusions
- dimensional analysis: variance analysis (part vs. CAD)

Used µCT system: vtomex l 300
Additive Manufacturing – example for CT analysis SLM method

3D CT image
nominal-actual comparison (part vs. CAD)
Used µCT system: vtomex l 300

By courtesy of
Additive Manufacturing – example for CT analysis SLM method

3D CT image
nominal-actual comparison
Part A vs. Part B

Used μCT system: vtomex I 300
Additive Manufacturing – example for CT analysis AM metal powder

Workpiece #3: Titan powder

3D CT image

Voxel size 1.4 µm

Used µCT system: nanotom m
Additive Manufacturing – example for CT analysis AM metal powder

Workpiece #3: Titan powder

3D CT image

Size distribution

Voxel size 1.4 µm

Used µCT system: nanotom m
Additive Manufacturing – example for CT analysis AM metal powder

Workpiece #3: Titan powder

CT statistics

Size distribution

Voxel size 1.4 µm

Used µCT system: nanotom m
Additive Manufacturing – example for CT analysis AM metal powder

Workpiece #3: Titan powder

CT 3D image

Void distribution

Voxel size 1.4 μm

Used µCT system: nanotom m
Additive Manufacturing – example for CT analysis AM metal powder

Workpiece #3: Titan powder

CT statistics

Void distribution

Voxel size 1.4 µm

Used µCT system: nanotom m
Workpiece #3: Titan powder

XY slice movie

Void distribution

Voxel size 1.4 µm

Used µCT system: nanotom m
Additive Manufacturing – example for CT analysis AM metal powder

Workpiece #3: Titan powder

2D cut slices and 3D view

Inclusion/Particle detection

Voxel size 1.4 µm

Used μCT system: nanotom m
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Computed Tomography (CT) is a leading technique for non-destructive testing (NDT) of additively manufactured (AM) workpieces and complementary to other techniques in use (in-situ visual inspection, coordinate measuring machine (CMM))

The classical casting/molding defect types will be substituted by much smaller and new types of failures in AM to be detected by NDT

Computed tomography fits the AM industry’s needs for quality assurance, if it delivers enough X-ray energy, contrast, resolution & speed

Automatic workflows as enabler to production based control and in communication with other NDT techniques for AM parts are crucial

Apart from the standardization work already done, ISO and ASTM will need to establish guidelines for CT utilization/interpretation. Waygate Technologies will be continuously supporting the ASTM WK 47031 Workgroup
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