Utilising Computed Tomography in Additive Manufacturing (AM)

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CT scan of a LZN printed Concept Plane Toys
Fast track printing of aluminum, lowest quality

Courtesy of
Outline

CT Principle

Added Values of CT in Additive Manufacturing

Example CT Results on AM workpieces

Conclusion
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Aero X-ray applications & solutions

Increasing X-ray inspection requirements driving change

Technology Introduction

Computed Tomography

Assisted Defect Recognition

Broad Acceptance

Industry Standards
New X-ray/CT Technologies: Highlights

X-ray detectors

- Dynamic 41/100 digital detector
- GE’s superior image quality X-ray detector for 20 radiographic inspection and high-resolution CT

Key features & benefits
- High sensitivity and high contrast
- Excellent image quality
- Adaptive detection algorithm for optimal image
- Hi-speed X-ray technology

X-ray sources

- High-flux target
- For up to 2 times faster microCT scans or doubled resolution

Key features & benefits
- High-flux target for improved target sensitivity
- Enhanced image quality

X-ray Imaging

- Scatter correction
- Unique tool for high quality scatter reduced industrial CT
- Scans acquired in significantly shorter scan time

Key features & benefits
- Scatter correction algorithm
- Enhanced image quality

Robotics & Automation

- High-speed robotic arm
- Precision and accuracy in imaging

Key features & benefits
- Advanced robotics technology
- High-speed automation

Baker Hughes, a GE company
CT Principle – video sequence

Please watch here: https://www.youtube.com/watch?v=ozH_zAgDuFE
CT Principle

cone & fan beam, scatter|correct

- Cone beam CT (3D) is fast but scattered radiation can affect the image quality
- Fan beam CT is not affected by scattered radiation but is slow

GE’s scatter|correct utilizes the advantages of both methods
CT Principle: cone & fan beam, scatter\correct

scatter\correct application examples, turbine blade

CT slice without scatter\correct thickness measurement NO

CT slice with scatter\correct thickness measurement YES
CT Principle

If the entire sample diameter $d$ is scanned with a detector $D$ of $N$ pixels, the voxels size is limited to $V = \frac{d}{N}$.

In an ROI (region of interest) scan, only a cylinder of diameter $d'$ is scanned, leading to a smaller voxel size and higher resolution (if the geometric unsharpness $U_g$ allows this):

$$V' = \frac{d'}{N}$$

In case the sample is very broad, the rotation angle might be restricted to less than 360°. Down to about 270°, a good image quality may still be expected.
CT Principle - critical parameter voxel resolution

- inspection on four different length scales, e.g. casting

**Complete casting:**
1) 150 µm Voxelsize, microfocus: macroporosities, metrology
2) 30 µm Voxelsize, microfocus: microporosities

**Subsection of casting:**
3) 3 µm Voxelsize, microfocus tube: detailed analysis of micropores
4) 0.5 µm Voxelsize, Nanofocus tube, high resolution 3D materialography
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Aerospace AM applications

Structurals, turbochargers, nozzles, brackets...

...blades, CMC workpieces
Additive Manufacturing – where and how computed tomography (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

- standardisation organisations:
  -> perform CT measurements to help defining guidelines in volumetric inspection, complementing to standard NDT techniques for surface and below surface inspection (eg. UT, EC)
Additive Manufacturing – Principle - Workflow

Much more than just printing!

3D CAD Model ➔ Prep for Process ➔ AM Process ➔ Thermal Processing ➔ Post Processing and Inspection ➔ Final Part

CT

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Additive Manufacturing – Principle - Automation
Showcase: collaborative robot with CT scanners

- Flexible and extendable for up to 4 automatic CT Systems
- Robot based part handling with Automated Guided Vehicles
- Compact for optimized floor space
- Flexible interface to Brilliant Manufacturing IT system
Additive Manufacturing – applicable standards (ASTM)

American Society for Testing and Materials (ASTM) Standards

ASTM International Technical Committee F42 on AM Technologies is a non-profit organization working on AM. The scope of the committee is to promote knowledge, stimulate research and implement technology through the development of standards for additive manufacturing technologies. Standards developed by F42 are:

- F2792 Standard Terminology for Additive Manufacturing Technologies
- F2915 Standard Specification for Additive Manufacturing File Format (AMF)
- F2921 Standard Terminology for Additive Manufacturing–Coordinate Systems and Nomenclature

A proposed new ASTM International standard will serve as a guide to determine specific mechanical properties of materials made with an AM process. WK43112, Guide for Evaluating Mechanical Properties of Materials Made via Additive Manufacturing Processes, is being developed by Subcommittee F42.01 on Test Methods, part of ASTM International Committee F42 on AM Technologies.

In addition to WK43112, F42.01 is currently developing two other proposed standards:

- WK30107, Practice for Reporting Results of Testing of Specimens Prepared by Additive Manufacturing

-> WK47031: CT Workgroup
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Additive Manufacturing – example for CT analysis
SLM method

Workpiece #1:
Medical rotary carousel for test tubes
Material: AlSi10Mg
Dimensions (LxWxH):
Additive Manufacturing – example for CT analysis
SLM method

2D slices and 3D rendered image:
Visualisation of QR code and powder entrapments

Used µCT system:
v|tome|x m 300

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

Workpiece #2:
Reaction wheel bracket (ESA)
Material: AlSi10Mg
Motivation to implement AM:
weight reduction (-60%), optimised topology
Additive Manufacturing – example for CT analysis
SLM method

3D image:
nominal-actual comparison
(part vs. CAD)

Used µCT system:

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

3D image: nominal-actual comparison (partA vs. PartB)

Used μCT system:
Additive Manufacturing – example for CT analysis
SLM method – ROI scan

Region of Interest (ROI)

2D slice and 3D rendered image:
- borehole shape,
- inclusions,
- pore orientation

Used μCT system:

By courtesy of DMRC
Additive Manufacturing – example for CT analysis
SLM method – ROI scan – porosity analysis

By courtesy of

[Image of 3D model with measurement tables]
Additive Manufacturing – example for CT analysis
AM metal powder

Workpiece #4: Powder

SEM images

Left: new powder

Right: new & recycled powder

Inconel 718 -> SLM powder (new/recycled)

<- Ti6Al4V
EBM powder (new/recycled)

By courtesy of ACCESS
Additive Manufacturing – example for CT analysis
AM metal powder

2D slice & 3D view: pores, particle absorption and distribution, morphology, sphericity

Used µCT system: v|tome|x m 300

By courtesy of access
Additive Manufacturing – example for CT analysis
AM metal powder

Image stack:
Particle size analysis

Used µCT system:
\( v|tome|x \) m 300

By courtesy of

https://geog.my.salesforce.com/sfc/p/A0000000QC05/a/12000000DvHN/\_1PeZd3V8F.rbGE0F3cLBh1Frrwo0j.4qZnsh.OZ3ck
Additive Manufacturing – example for CT analysis
AM metal powder

Image stack:
Particle size analysis
(coloured segmentation)

Used µCT system:
v|tome|x m 300

By courtesy of
https://geog.my.salesforce.com/sfc/p/A0000000QC05/a/12000000DvHS/eySaWLkWUxq_sgV5yUosSkPNzov7stYO_cRnvGg
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- Computed Tomography is a leading NDT technique for non-destructive testing of additively manufactured workpieces and complementary to other techniques in use (e.g. in-situ visual inspection, CMM).

- The classical casting/moulding 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 NDT and in communication with other NDT techniques for AM parts are critical.

- Apart from the standardisation work already done, ISO and ASTM will need to establish guidelines for CT utilisation/interpretation. GE Digital Solutions will be continuously supporting the ASTM WK 47031 Workgroup.
Announcement

Visit GE Inspection Technologies at formnext

Come and see our innovative automated CT inspection solution „v|tome|x m 300“ in hall 3.1, booth # D28.

Register here for a free entry ticket: https://www.mesago.de/en/formnext/For_visitors/Tickets/index.htm
Acknowledgements

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Thank you very much for your attention!

More information at www.gemeasurement.com/CT
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