NDT for AM at MTC

BINDT AM for Aerospace Workshop

Ben Dutton

1st October 2024

mtc events

Contents

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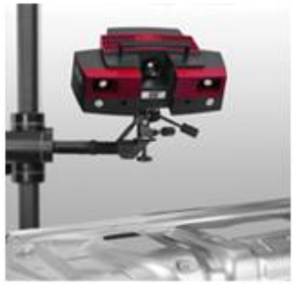
Metrology and NDT Equipment at the MTC

Dimensional Metrology

High-precision tactile instruments

High-precision optical instruments

Portable tactile instruments



Portable optical Instruments

Surface Metrology

Tactile surface measurement

Optical surface measurement

Portable surface measurement

Microscopes

Non-destructive Testing

3D Computed Tomography

Computed Radiography

Portable NDT (phased array ultrasound, eddy current array)

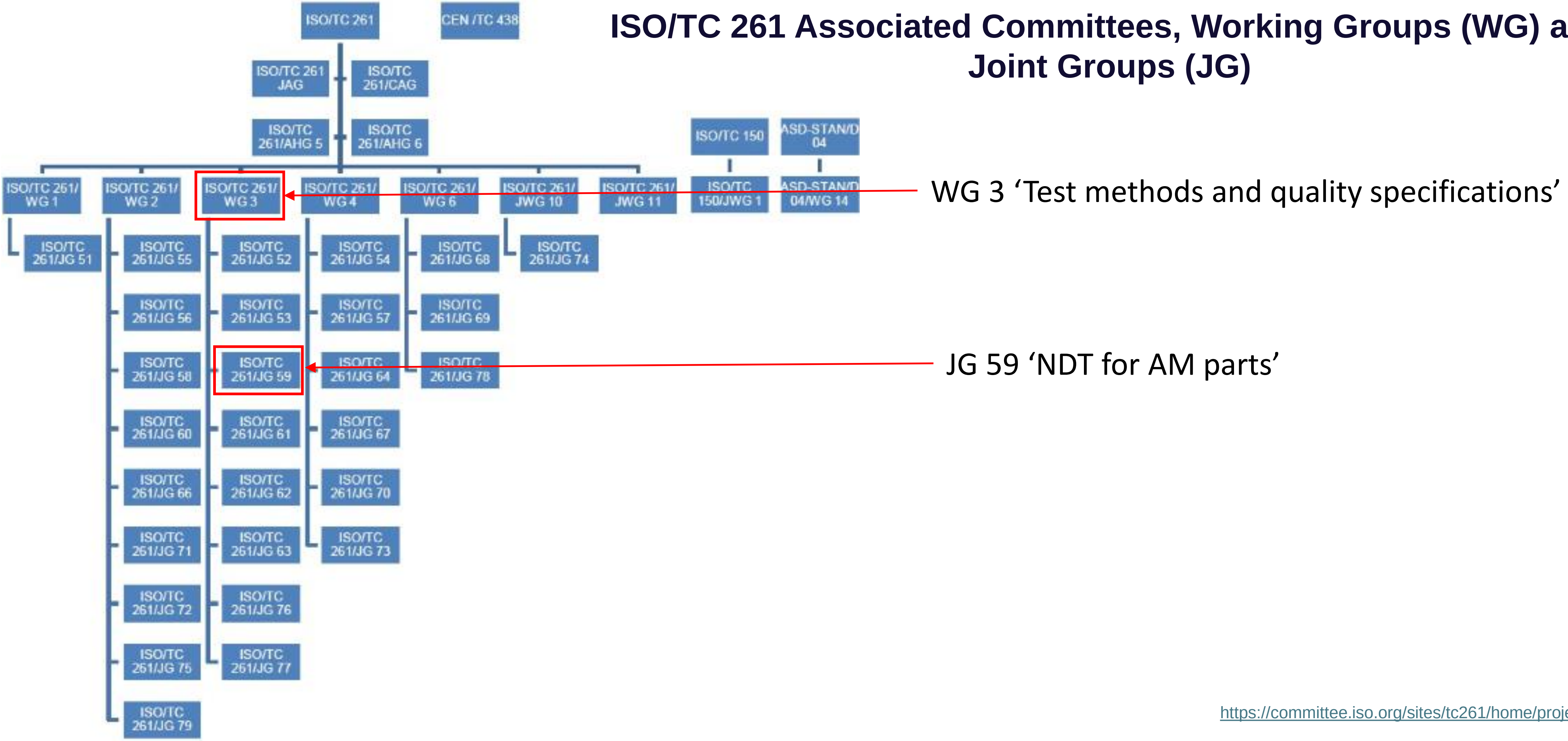
Non-contact laser ultrasound inspection

+ XBS, GPR, Thermography

A selection of equipment and inspection capabilities, at the MTC.

ISO TC261/ASTM F42 JG59 NDT for AM

ISO/TC 261 Associated Committees, Working Groups (WG) and Joint Groups (JG)



https://committee.iso.org/sites/tc261/home/projects.html

ISO TC261/ASTM F42 JG59 'NDT for AM Parts'

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Scope

ISO/TC261/JG59 'NDT for AM' is a Joint Group for non-destructive testing of additive manufactured parts, including defect classification and processes to intentionally seed flaws in parts and artefacts, covering metallic parts for several sectors and a similar framework can be applied to other materials such as ceramics and polymers, etc.

Published

- ISO TC261/ASTM F42 JG59 TR **52905:2023**, '**Additive Manufacturing — Non-Destructive Testing and Evaluation — Standard Guideline for Defect Detection in Metallic Parts**' (Led by B. Dutton) https://www.iso.org/standard/82539.html
- ISO TC261/ASTM F42 JG59 TR **52906:2022**, '**Additive Manufacturing — Non-Destructive Testing and Evaluation — Standard Guideline for Intentionally Seeding Flaws Metallic Parts**' (Led by B. Dutton) Published https://www.iso.org/standard/75716.html
- ASTM version is ISO/ASTMTR52906-EB https://www.astm.org/iso-2fastmtr52906-eb.html

Active

- ISO TC261/ASTM F42 JG59 NP **52958** '**Additive Manufacturing of Metals—Powder Bed Fusion (PBF)— Best Practice for In-Situ Flaw Detection and Analysis for Laser-based PBF**' (Convener: B. Dutton, author: Ehsan Toyserkani) Editing
- ISO TC261/ASTM F42 JG59 NP **52948** '**Additive manufacturing for metals — Non-destructive testing and evaluation — Imperfections classification in PBF parts**' (Convener: B. Dutton, author: Christophe Grosjean) Re-Balloting
- ISO TC261/ASTM F42 JG59 NP **52969** '**Additive manufacturing for metals — Non-destructive testing and evaluation — Imperfections classification in DED parts**' (Convener: B. Dutton, author: Didier Boisselier) New active project
- Registration of ISO/ASTM PWI "Additive manufacturing - NDT - Dimensional measurements on XCT images" New proposed project

ASTM CoE

mtc events

Published (not NDT)

- ASTM **F3530-22** 'Standard Guide for Additive Manufacturing — Design — Post-Processing for Metal PBF-LB' Farhan/Andrew T https://www.astm.org/f3530-22.html
- **F3522** Standard Guide for Additive Manufacturing of Metals — Feedstock Materials — Assessment of Powder Spreadability (astm.org) Steven Hall
- F3592 Standard Guide for Additive Manufacturing of Metals – Powder Bed Fusion – Guidelines for Feedstock Re-use and Sampling Strategies (astm.org) Steven Hall

Active (not NDT)

- ASTM CoE funded project for WK66030 'New Guide for Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing', led by Steven Hall, 4 negatives planned to deal by end of 2024
- ASTM CoE funded project for WK75265 'New Guide for Additive Manufacturing of Polymers -- Powder Bed Fusion -- Guidelines for Feedstock Recycling and Sampling Strategies', led by Ed Cant, addressing negative votes
- ASTM CoE funded project for WK80171 'New Guide for Additive Manufacturing of Metals -- Feedstock Materials -- Measurement and Classification of Feedstock Contamination', led by Aneta Chrostek-Mroz, balloting
- ASTM CoE funded project for WK85121. 'Standard Practice for Nondestructive Examination of Polymeric and Nonmetallic Additively Manufactured Parts After Build', led by Wilson Vesga, generating 1st draft

Active (NDT)

- ASTM CoE funded project for WK85121. '**Standard Practice for Nondestructive Examination of Polymeric and Nonmetallic Additively Manufactured Parts After Build**', led by Wilson Vesga, generating 1st draft

Other Contributions/Participations

Published

- ASTM **E3166** (E07 WK47031), '**New Guide for Nondestructive Testing of Metal Additively Manufactured Metal Aerospace Parts After Build**'
- ASTM **E3353-22**, '**Standard Guide for In-Process Monitoring Using Optical and Thermal Methods for Laser Powder Bed Fusion**'
- BSI **PAS 6011:2020** '**Non-destructive testing (NDT) for use in directed energy deposition (DED) additive manufacturing processes – Guide**' https://knowledge.bsigroup.com/products/additive-manufacturing-non-destructive-testing-for-use-in-directed-energy-deposition-guide?version=standard

Active

- ISO/TC 261/ASTM F42 JG76, WD 52927:2020(E) '**Additive manufacturing — General principles — Main characteristics and corresponding test methods**'
- WK75329 – '**New Practice for Nondestructive Testing (NDT), Part Quality, and Acceptability Levels of Additively Manufactured Laser Based Powder Bed Fusion Aerospace Components**'

Post Built NDT Potential

Methods capability for a simple block with machined surface finish

Class	Type	Sub-type	Including…	Surface breaking cracks / lack-of-fusion	Surface breaking voids	Internal cracks / lack-of-fusion / layer defects	Isolated / clustered porosity	Internal voids, incl. cross-layer defects	Inclusions	Trapped powder (Powder Bed Fusion only)	Near surface microstructure variation	Sub-surface microstructure variation	Near surface residual stress	Sub-surface residual stress
Mechnical	Ultrasonic	Contact or near-contact (air-coupled)	Single / twin / array probe, Time of Flight Diffraction	●●●	●●●	●●●	●●●	●●●	●●●	●●●				
Mechnical	Ultrasonic	Immersion		●●●	●●●	●●●	●●●	●●●	●●●	●●●				
Mechnical	Vibration analysis	Resonance testing	Acoustic pattern recognition	●●	●●	●	●	●●		●●				
Optical / visible light	Simple		Aids such as lighting / boroscope etc.	●●	●●●					●●●				
Optical / visible light	Dye-penetrant		Fluorescent / visible	●●●	●●●									
Radiographic	X-ray	Conventional, 2D	Film / Computed / Real-time / Digital	●●	●●●	●●	●●●	●●●	●●●	●●●				
Radiographic	X-ray	Computed Tomography	2D (fan beam) / 3D (cone beam) CT / Laminography	●●	●●●	●●	●●●	●●●	●●●	●●●				
Radiographic	X-ray	Diffraction									●●		●●●	●
Thermal	Optically excited	Flash			●			●		●●				
Thermal	Optically excited	Laser		●●●	●●	●		●		●●				
Thermal	Electrically excited		Induction-heated	●●●	●●●	●		●		●●				
Thermal	Vibrationally excited		Thermosonics	●●●	●	●●●		●●						
Electromagnetic	Eddy current		Single / array probe	●●●	●●						●●●			
Electromagnetic	Magnetic field	Magnetic particle		●●●	●●●									
Electromagnetic	Magnetic field	Barkhausen									●●	●●		
Electromagnetic	Magnetic field	Alternating Current Field Measurement		●●●	●●●									
Mixed	Eletromagnetic-Mechanical	Electromagnetic Acoustic Transducer Ultrasound		●●●	●●●	●●●	●●●	●●●	●●●	●●●				
Mixed	Optical-Mechanical	Laser Ultrasound		●●●	●●●	●●	●	●●	●	●				
Mixed	Optical-Mechanical	Spatially Resolved Acoustic Spectroscopy		●●●	●●●						●●●			
Mixed	Optical-Mechanical	Shearography	Electronic speckle pattern interferometry	●●●	●●●	●●	●	●●		●●				
Mixed	Optical-Mechanical	Laser Speckle Photometry		●	●	●		●		●	●●			
Mixed	Optical-Mechanical	Grazing Incidence Ultrasound Microscopy		●●	●●						●●●			

The tool shows that commonly used NDT methods such as **Contact/immersion UT and die penetrant** for bulk and surface breaking defects respectively, would be capable**.**

Post Built NDT Potential

Methods capability for a complex lattice structure and as built surface condition

The tool shows that the most appropriate NDT method for the majority of defects is **X-ray computed tomography and resonance testing.**

Class	Type	Sub-type	Including…	Surface breaking cracks / lack-of-fusion	Surface breaking voids	Internal cracks / lack-of-fusion / layer defects	Isolated / clustered porosity	Internal voids, incl. cross-layer defects	Inclusions	Trapped powder (Powder Bed Fusion only)	Near surface microstructure variation	Sub-surface microstructure variation	Near surface residual stress	Sub-surface residual stress
		Contact or near-contact (air-coupled)	Single / twin / array probe, Time of Flight Diffraction											
	Ultrasonic	Immersion												
Mechnical	Vibration analysis	Resonance testing	Acoustic pattern recognition	■■	■■	■	■	■■		■■				
	Simple		Aids such as lighting / boroscope etc.		■■					■■				
Optical / visible light	Dye-penetrant		Fluorescent / visible											
		Conventional, 2D	Film / Computed / Real-time / Digital		■■		■■	■■	■■	■■				
		Computed Tomography	2D (fan beam) / 3D (cone beam) CT / Laminography	■	■■■	■	■■■	■■■	■■■	■■■				
Radiographic	X-ray	Diffraction												
		Flash						■		■				
	Optically excited	Laser		■	■	■		■		■				
	Electrically excited		Induction-heated											
Thermal	Vibrationally excited		Thermosonics	■■	■	■■		■						
	Eddy current		Single / array probe											
		Magnetic particle												
		Barkhausen									■			
Electromagnetic	Magnetic field	Alternating Current Field Measurement												
	Eletromagnetic-Mechanical	Electromagnetic Acoustic Transducer Ultrasound												
		Laser Ultrasound		■■	■■			■	■					
		Spatially Resolved Acoustic Spectroscopy		■	■									
		Shearography	Electronic speckle pattern interferometry	■■	■■	■		■		■				
		Laser Speckle Photometry		■	■	■		■		■				
Mixed	Optical-Mechanical	Grazing Incidence Ultrasound Microscopy												

Courtesy AMAZE EU project

Post Build NDT: Emerging Method

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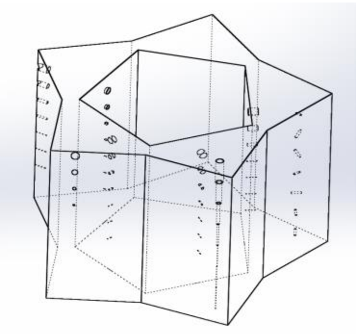
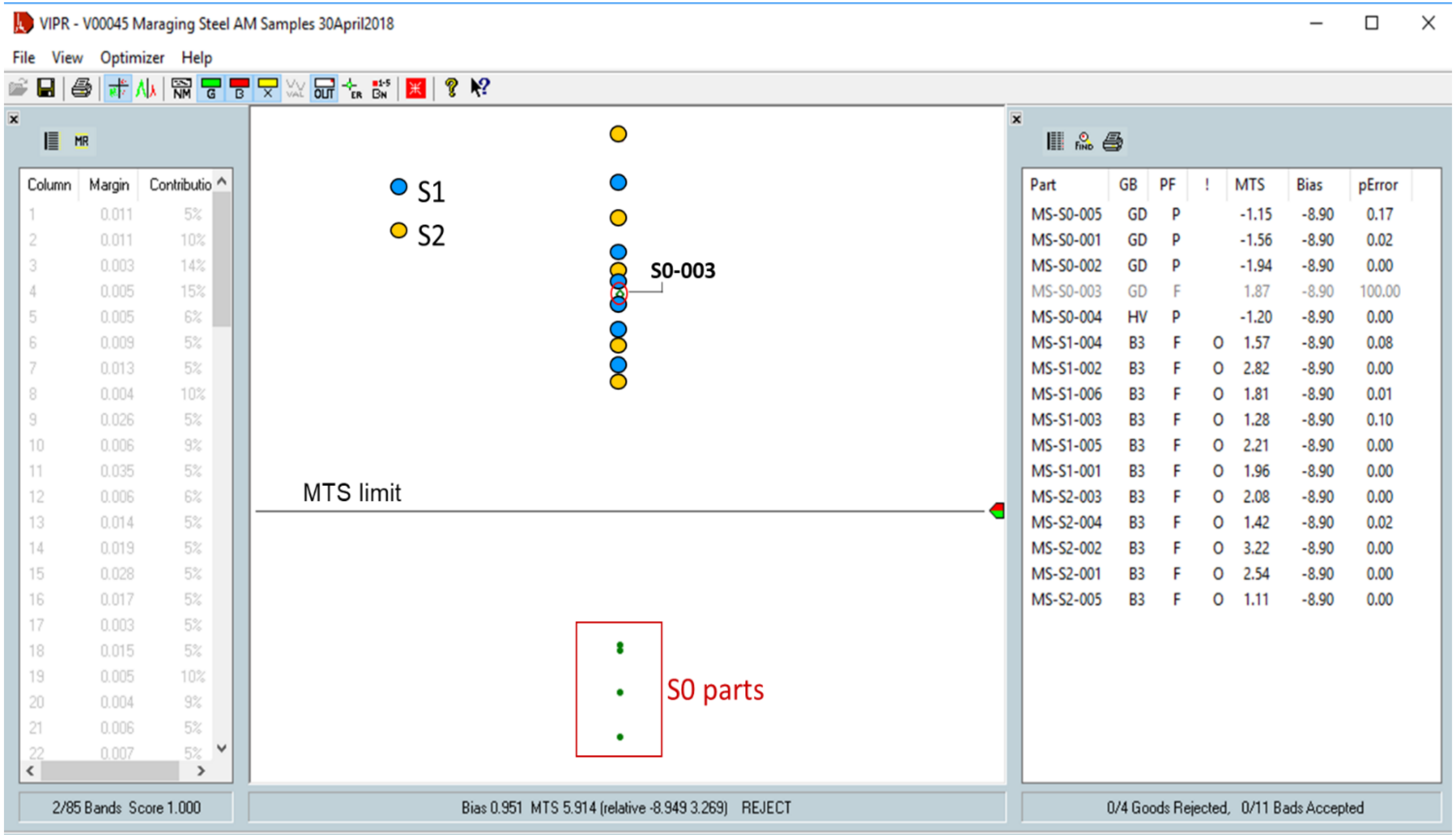
Process Compensated Resonance Testing (PCRT)

- PCRT demonstrated capability to differentiate between seeded (S1 & S2) and the non-seeded defect (S0) star artefacts.
- RAM had similar results.



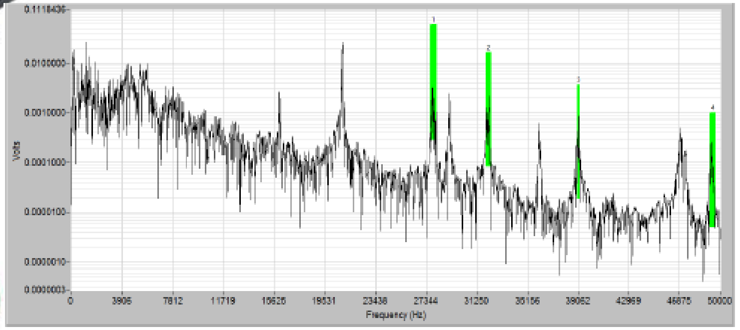


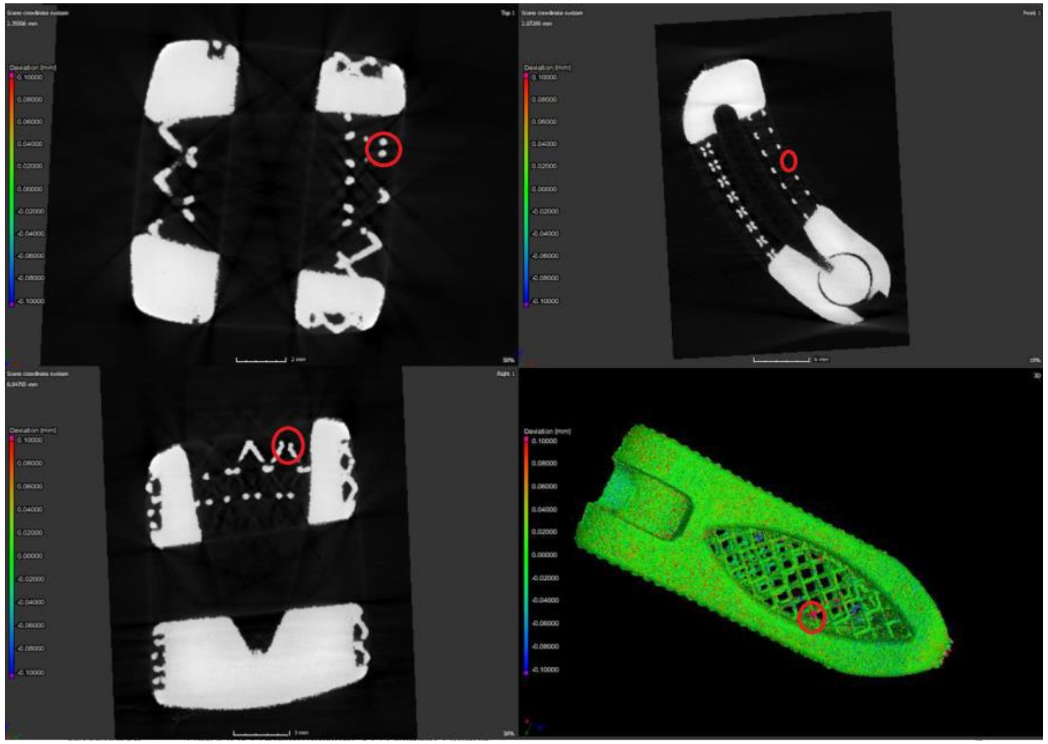
Courtesy ISO/ASTM JG59 TR 52905, ‘Additive Manufacturing — Non-Destructive Testing and Evaluation — Standard Guideline for Defect Detection in Metallic Parts’

Post Build NDT: Emerging Method

RAM Tests on Lattice Parts

- All parts that displayed visible defects (broken struts) failed with RAM method, others passed.
- Part 15 did not display visible defect but also failed. After XCT tests a broken strut was found.





Total: 14 parts, tested 3 times each

Part#	Part Description	Passed	Failed
7,8,9,10,15,17,19,20	Good	7	1 (part 15)
1,4,5,6,11,18	Visible Defects	0	6

Courtesy ICWAM, Metz 5-6 June 2019, A-F. Obaton

In-process Monitoring vs Inspection

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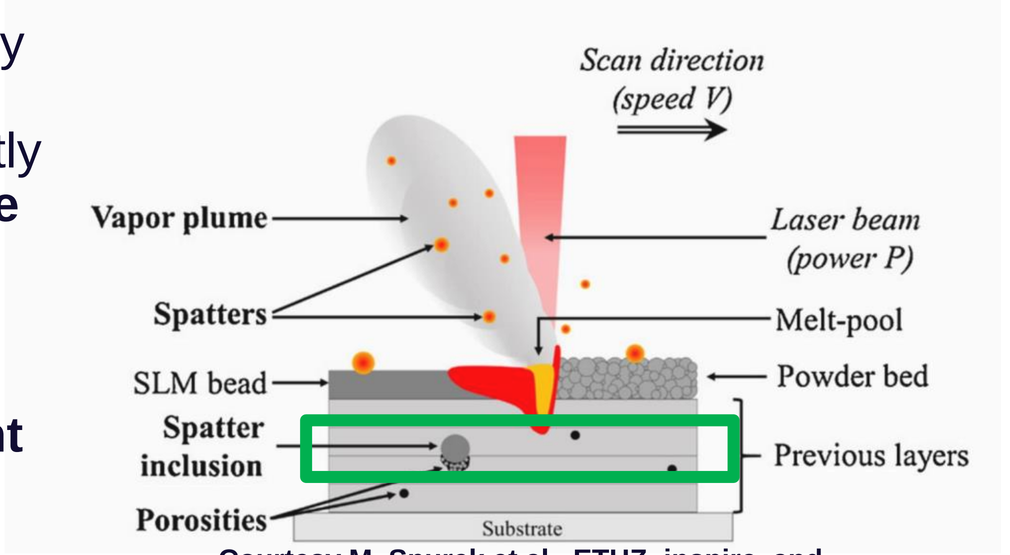
In-process Monitoring (Indirect) vs Inspection (Direct)

- In-process monitoring (**Indirect** Inspection) methods, monitor the process, and typically rely on optical and/or thermal methods. They can be improved with Modelling & ML, but **may miss the actual process change that created a defect**. These methods are mostly **surface based** detection and **following layers may heal or make them bigger by re-melting**.

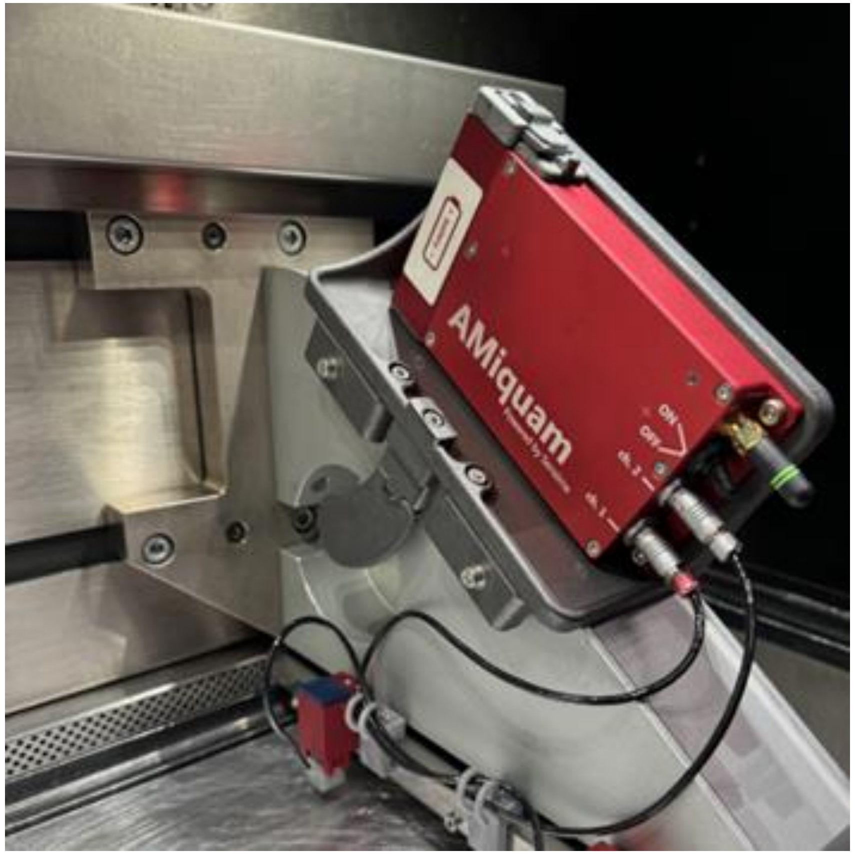
- In-process inspection (**Direct** Inspection) are **sensitive to both surface and subsurface defects**, where the latter are **permanent** and will not be eliminated, which are the ones that would be found on the **final part inspection**.



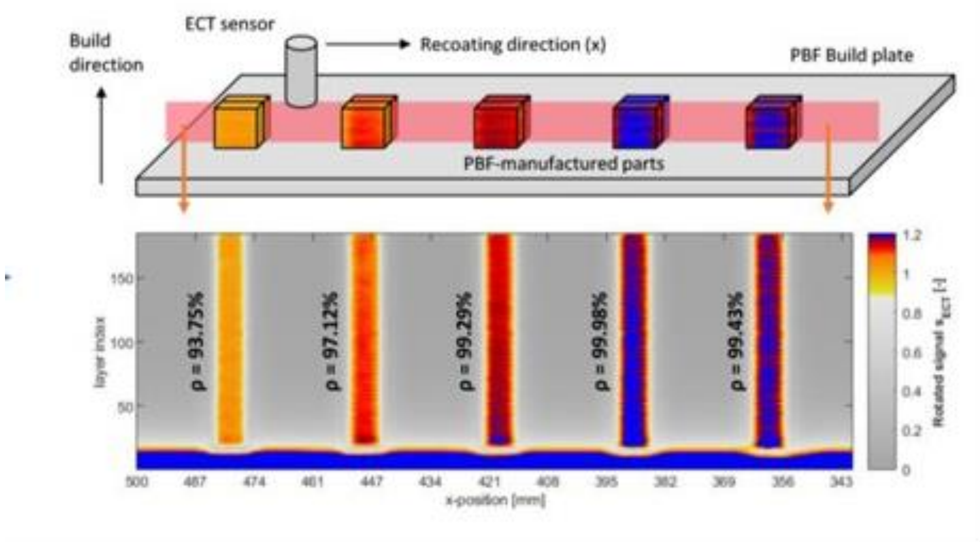
Courtesy M. Spurek et al., ETHZ, inspire, and AMiquam

In-process Inspection with EC

In-process (direct) inspection with EC



MTC has installed this system to assess its capabilities.

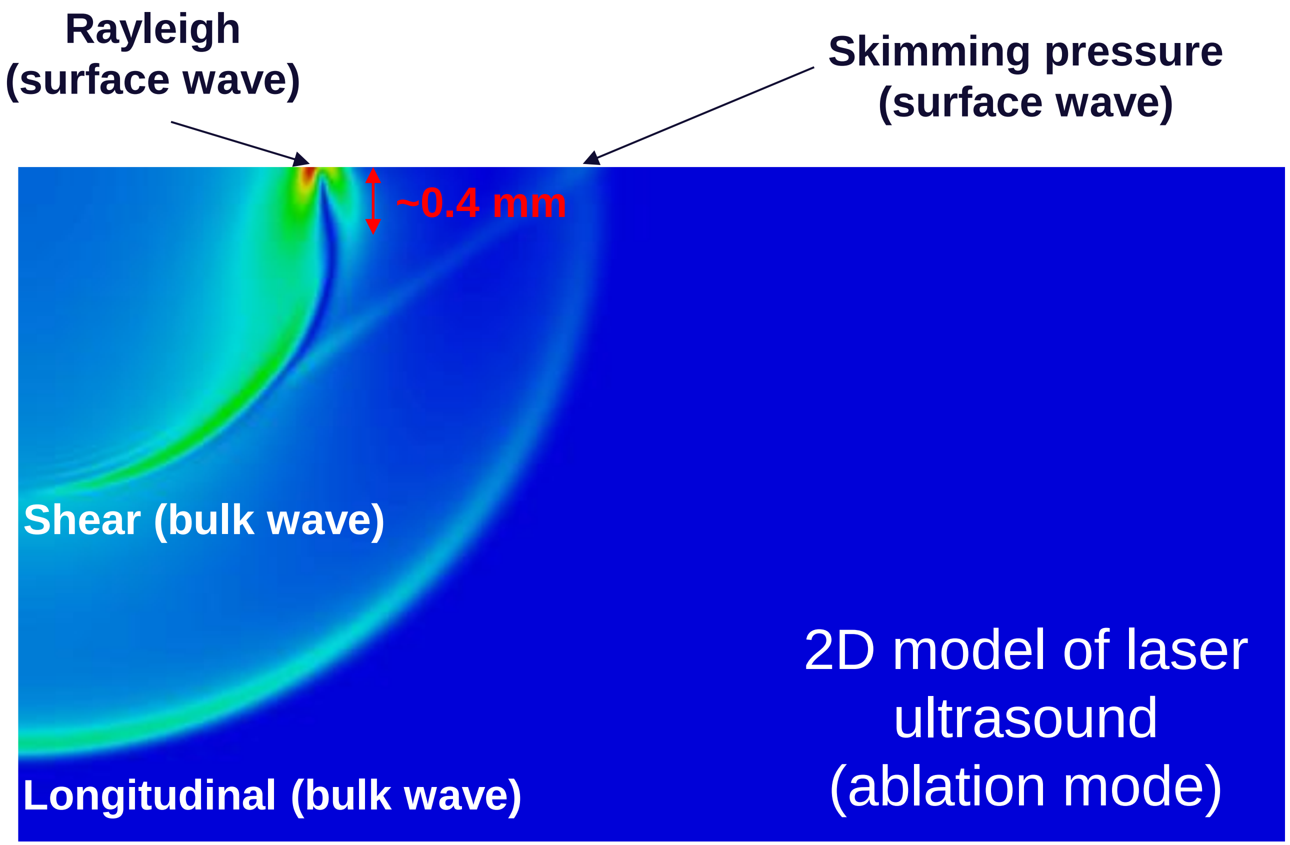


Visualisation
Cubes with different process parameters resulting in difference levels of density which corresponded to different levels of EC signal. (Calibrated against XCT and Archimedes)

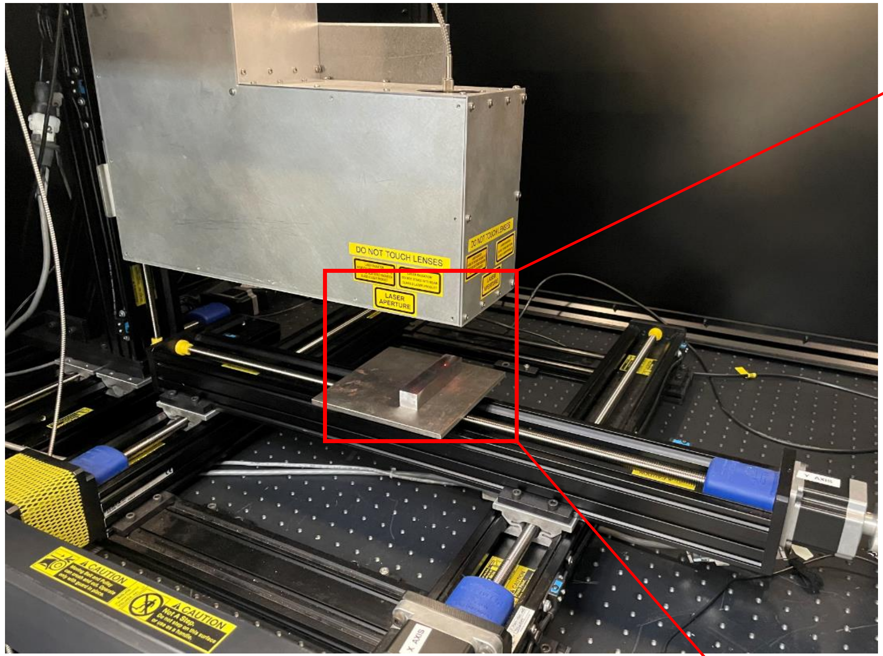
Courtesy M. Spurek et al., ETHZ, inspire, and AMiquam

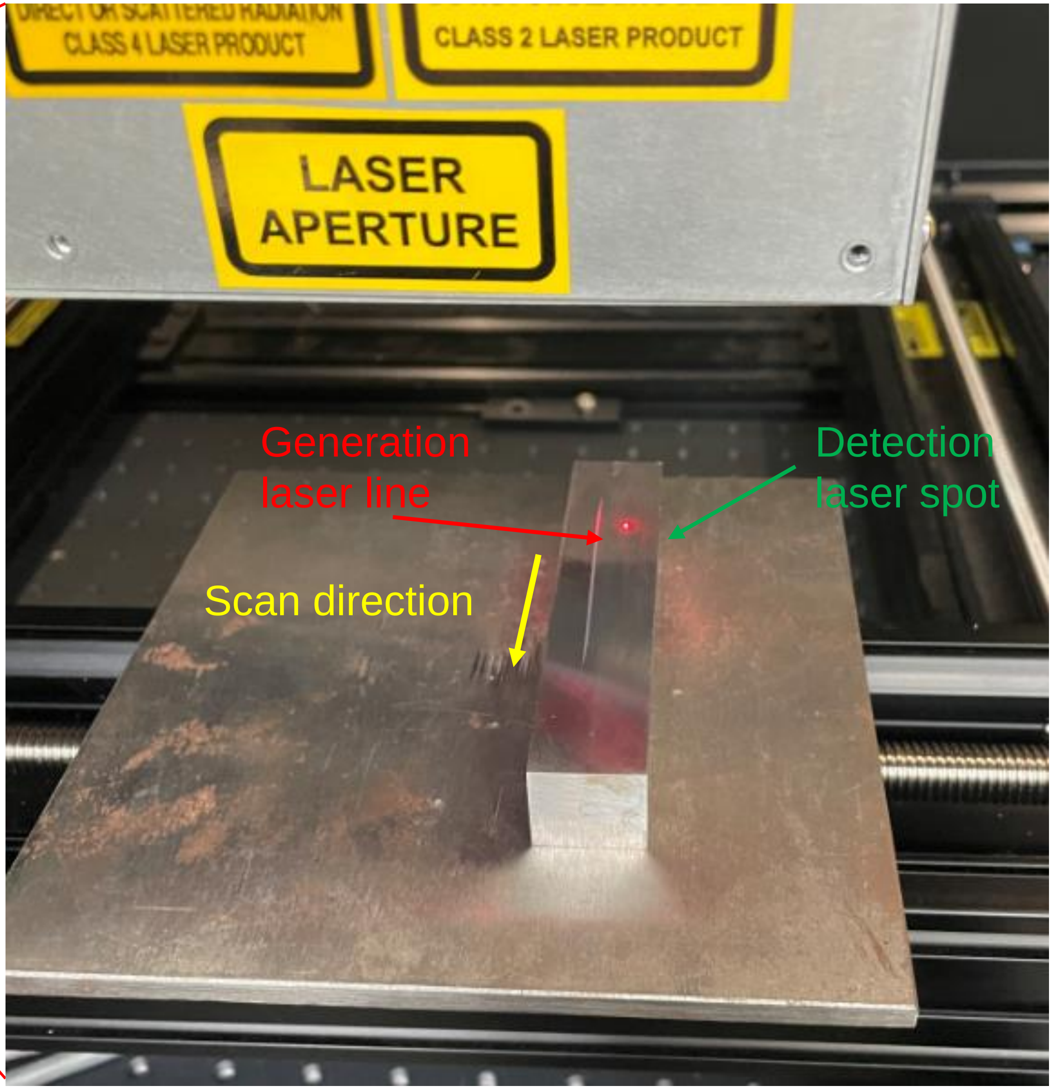
Early H2 Damage Detection with LUT

- Non-contact, non-invasive (no water or gel required), **high temperature capable**;
- More information can be extracted simultaneously by covering of both **surface and bulk and is wide bandwidth**;
- Suitable for **complex geometries** due to **small footprint** (200 µm laser spot diameter);
- Can handle **irregular surfaces** (max. angle to normal 40 deg);
- Sharper imaging and **better time of arrival** compared to contact UT (no ringing);
- Less energy than phased array (PA) contact UT.



Early H2 Damage Detection with LUT

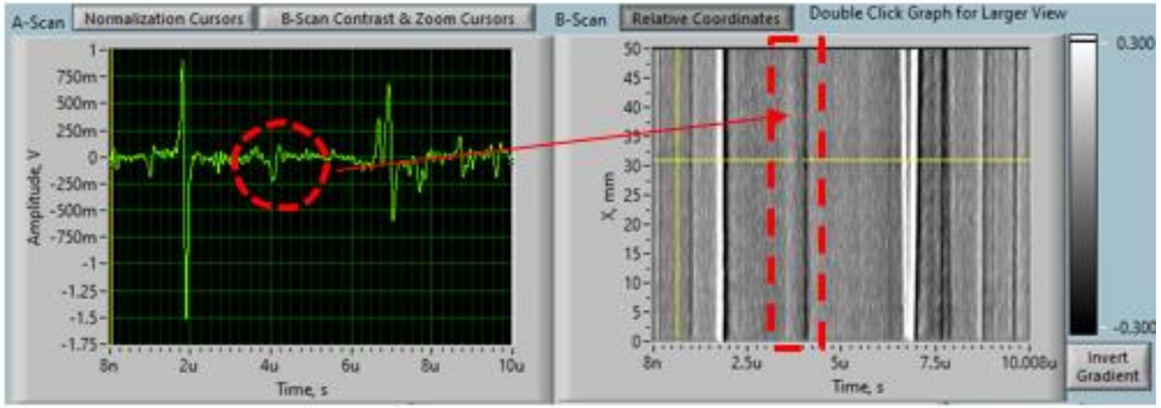




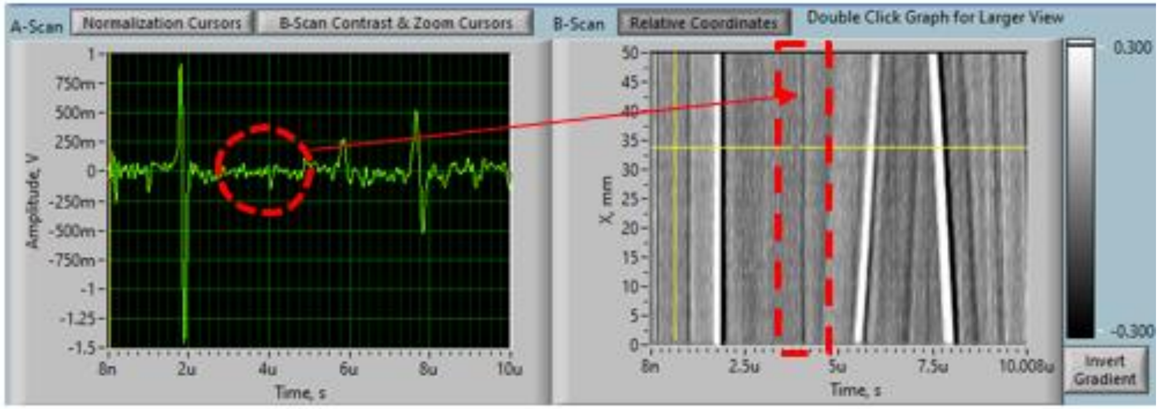
Laser beams positioned on the sample during the scan

Courtesy MTC CRP - HyENDT

Early H2 Damage Detection with LUT



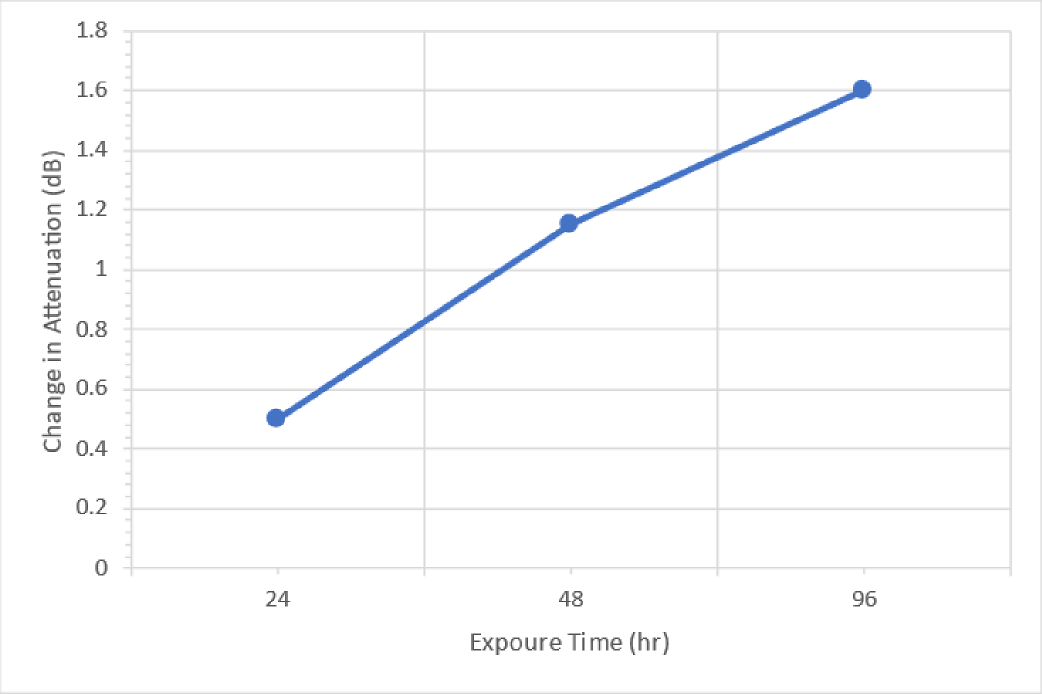
a) Sample 11 before exposure



c) Sample 11 after exposure

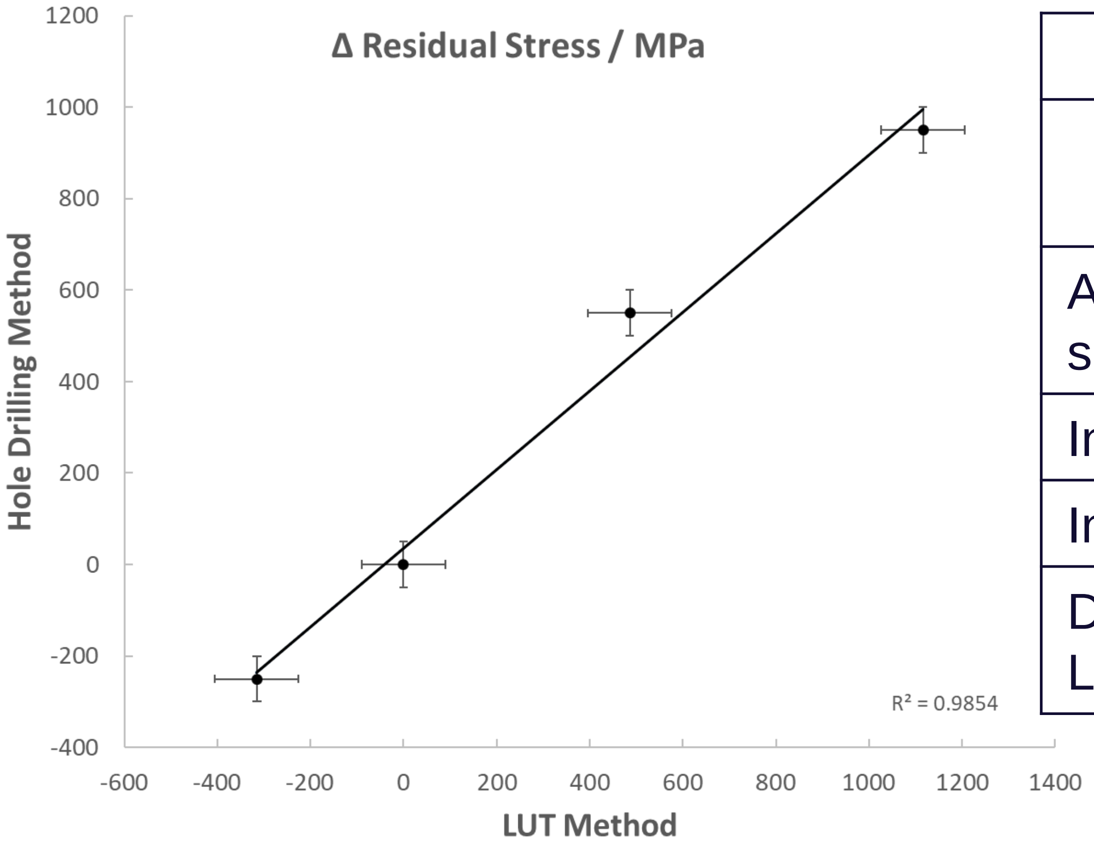
- **LUT Responses of sample as received (top) and after charging with hydrogen (bottom).**

- **No cracks or defects detected in the samples either prior to exposure to hydrogen or after charging.**
- **Despite there being no indications that could be directly linked to cracking, a surface wave mode attenuation was detected, which increased as the exposure time increased.**



Courtesy MTC CRP - HyENDT

Residual Stress (RS) Measurement with LUT



Δ Residual Stress Measurements (MPa)			
	LUT	Hole Drilling	Neutron Diffraction
Al (6082-T651) LSP samples	0 ± 90	0 ± 50	--
Inconel 718 sample 2.3	1116 ± 90	950 ± 50	--
Inconel 718 sample 1.3	486 ± 90	550 ± 50	--
Ductile Iron with/without LSP samples	-315 ± 90	-250 ± 50	-300 ± 50

LUT results correlate well with hole drilling and Neutron Diffraction residual stress measurement methods.

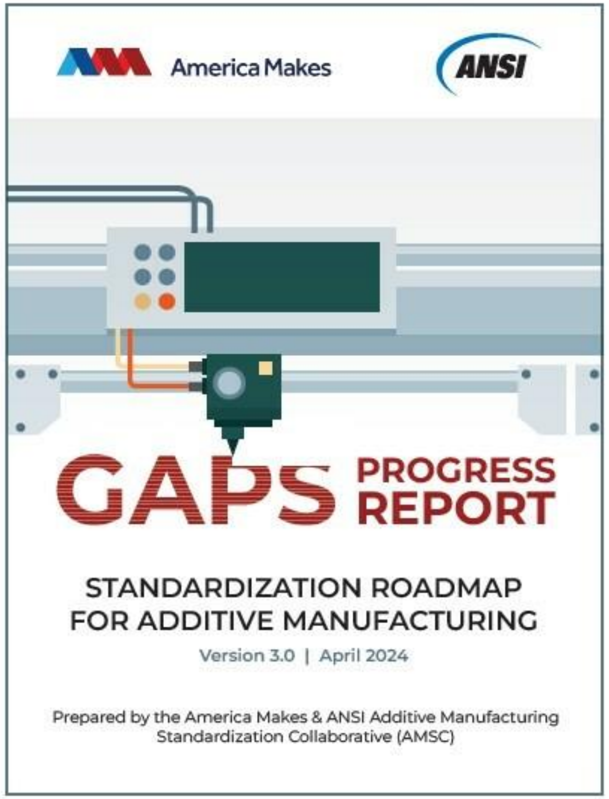
Other Standards Related Participations/Contributions

mtc events

Standards Roadmaps

Gaps Progress Report Available: America Makes and ANSI Publish (https://www.prnewswire.com/news-releases/gaps-progress-report-available-america-makes-and-ansi-publish-standardization-roadmap-for-additive-manufacturing-302124749.html?tc=eml_cleartime)

I review and update every year.



Other Standards Related Participations/Contributions

mtc events

Workshops

In-Situ Technology Readiness for Applications in AM Qualification and Certification 2nd ASTM AM CoE Specialty Workshop - AM CoE (https://amcoe.org/event/2ndspecialtyworkshop/)

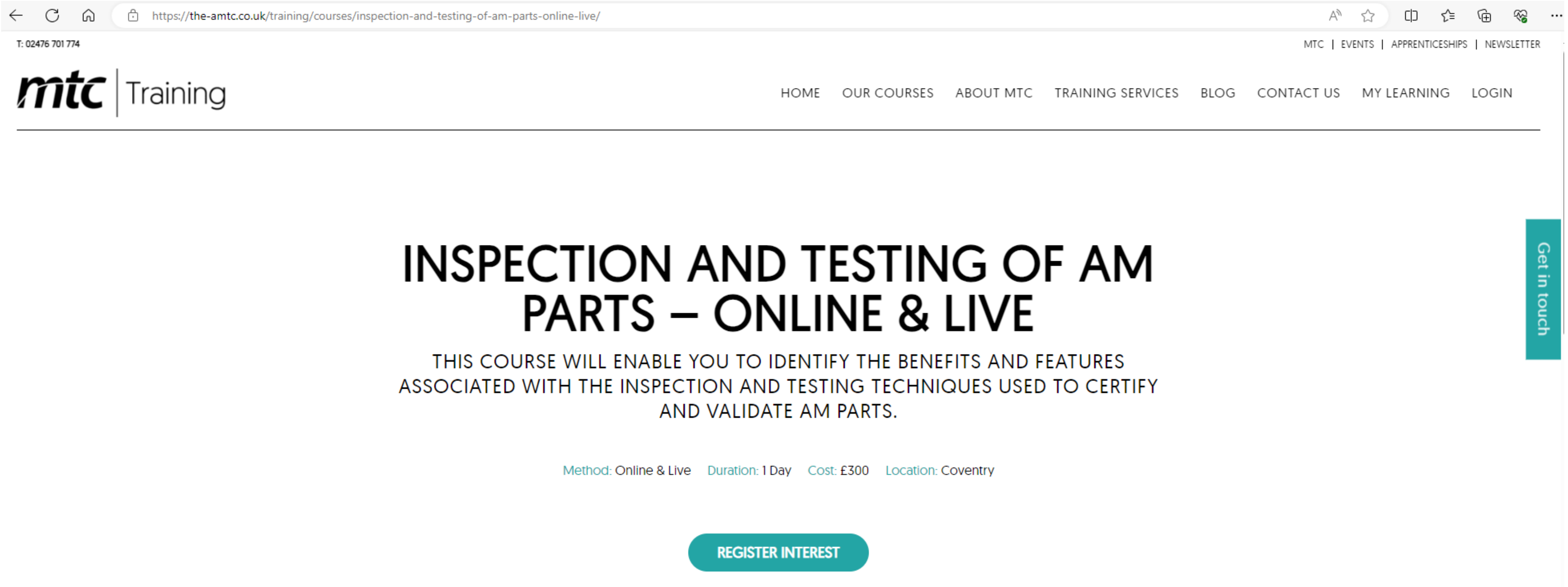
Participated and reviewed publication

Other Standards Related Participations/Contributions

mtc events

MTC Training

INSPECTION AND TESTING OF AM PARTS – ONLINE & LIVE
(https://the-amtc.co.uk/training/courses/**inspection-and-testing-of-am-parts**-online-live/)



Other Standards Related Participations/Contributions

ISO/TC 261 – ASTM F42 JGs, WG's and Plenary Meetings at The MTC 9 – 13 Sep 2024 (Co-sponsored/organised by MTC and BSI)

bsi Your partner in progress

7 August 2024

Dr. Ben Dutton
Manufacturing Technology Centre,
Ansty Park,
Pilot Way,
Coventry CV7 9JU

Our ref: ISO/ TC 261 Additive Manufacturing

Dear Ben,

On behalf of BSI, I would like to extend our heartfelt thanks for your outstanding support in co-hosting the ISO/ TC 261 Fall 2024 meeting held in Coventry during 9-13 September.

The Manufacturing Technology Centre is well-renowned for its research and technological advancement in manufacturing innovation. With its stellar network of industry leaders, enterprises and cutting-edge facilities, these undoubtedly demonstrate the UK's leadership and showcase success stories in this field.

We appreciate MTC's generosity of time and resources invested into the preparation and site tours and are delighted with the success of the meeting.

Yours sincerely,

Joy Tan
Senior Standards Manager

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Ben Dutton received recognition from BSI

Thank you

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