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UK RESEARCH CENTRE IN NDE

NDE for Additively Manufactured Components

Colin Brett, Technology Director

European Turbomachinery Network (ETN) Global October Workshop 2024
Stuttgart, Germany
10 October 2024






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Overview of Presentation

- Background and structure of RCNDE
- NDE projects for Additive Manufacturing




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What is it?

- A collaboration between universities and industry for the purpose of making an impact through NDE research and training
- Three guiding principles:
  - World-class scientific research;
  - Industrial benefit;
  - Impact on NDE profession
- Approaching ~70 Industrial, Academic & Associate members – multi sector in university partners
- Links to the Centres for Doctoral Training in Quantitative NDE and FIND CDT

8 University Members
(20+ multi-disciplinary research groups)

IMPERIAL	WARWICK THE UNIVERSITY OF WARWICK	University of BRISTOL	University of Nottingham UK | CHINA | MALAYSIA	MANCHESTER 1824 The University of Manchester	University of Strathclyde Glasgow	University of Southampton	UNIVERSITY OF LIVERPOOL
Guided ultrasonic waves Ultrasonics incl. sensors Electromag-netics	Ultrasound Sensors (eg EMATs, MEMS, etc) Ultrasonic tomography Electrostatic imaging	Ultrasound arrays and inversion Eddy-currents Muon tomography Composite inspection	Ultrasonic & optical methods Laser ultrasound Additive manufact-uring	Electro-magnetic tomography Quantum sensors Terahertz imaging XCT	Ultrasonics incl. arrays Robotics Laser ultrasound Ultrasonic inversion	X-ray X-ray computed tomography Thermal stress analysis Digital Image Correlation	Thermal stress analysis Digital Image Correlation

RCNDE Industrial Partners

14 Cross-sector Global Industrial Partners

	Airbus	Rolls-Royce	BAe Systems	DSTL	IHI	EDF	NDA	Jacobs	Hitachi	ONR	BP	Petrobras	MTC	EPRI
Aerospace	X	X	X	X	X								X	
Power					X	X	X				X			X
Nuclear		X			X	X	X	X	X	X				X
Defence	X	X	X	X									X	
Public Sector				X						X			X	
Oil & Gas								X			X	X		
Manufacturing	X	X	X		X				X				X	
Transport	X	X							X					
Civil						X	X	X					X	

RCNDE supply-chain Associate Members

NDE for Additive Manufacturing

- The research projects undertaken by RCNDE are determined by the needs of the industrial members

- 5-10-20 Year Vision of future requirements made every 5 years
  - Latest Vision produced in 2022
  - Insight, Vol. 64, No. 11, pp 625-632, November 2022

- The latest Vision produced a list of 34 main topics for research:
  - 5th ranked - Material composition and properties
  - 7th ranked - NDE for Additive Manufacturing

- NDE for AM is supported by Nuclear, Aerospace, Defence and Manufacturing sectors

- Board member MTC is the UK National Centre for AM

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Objectives for NDE of Additively Manufactured Components

- Want to inspect during manufacture to detect flaws and use information to take corrective actions
  - Avoid need for complex (re)inspections after the component has been completed
  - Amend the manufacturing process or scrap as soon as possible
  - Minimise time and cost

- Avoid need for applying gels/water to facilitate an inspection
  - Eliminate possibility of contamination
  - Ideally NDE should be contactless, fast and accurate

- Incorporate NDE within manufacturing equipment
  - Don’t want separate processes, if possible

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Relevant Projects

- **Inspection of** welds and **AM components during manufacture**
  - Contact ultrasonic testing, high temperature, compensation for effects of thermal gradients
  - **Contact ultrasonic inspection of WAAM component with automated repair**

- **Contactless inspection of components for defects**
  - **Laser Induced Phased Arrays (LIPA) inspection of a WAAM component**

- **Contactless measurement of material microstructure (grain properties)**
  - **SRAS (Spatially Resolved Acoustic Spectroscopy)**

- Verification of innovative AM processes and structures
  - X-ray tomography
  - Removal of artefacts caused by limited angle views of complex-shaped components

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Automated Inspection and Repair using Contact Ultrasonic Testing

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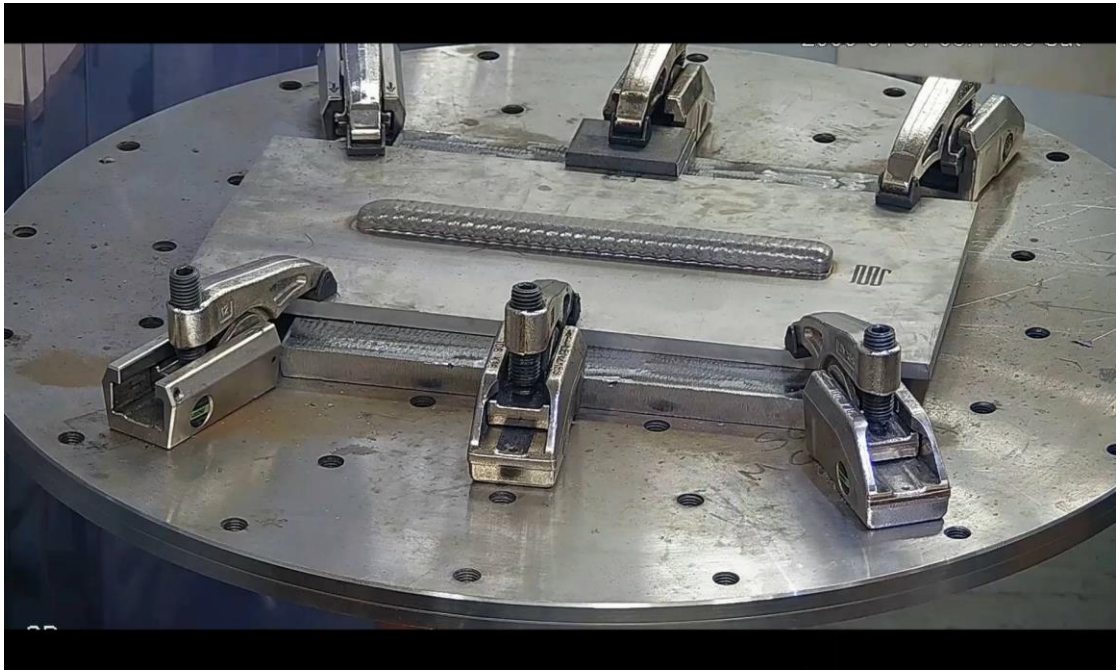
SEARCH
Sensor Enabled Automation Robotics & Control Hub

Integrated Demonstrator
In-Process Ultrasonic NDT for WAAM

University of Strathclyde Engineering

- x8 speed
- Ti 64 wall deposition with oscillation
- Roller probe inspection at circa 150 °C
- Artificial defects in wall



Cranfield University WAAM

Zimermann R,et al, Collaborative Robotic Wire + Arc Additive Manufacture and Sensor-Enabled In-Process Ultrasonic Non-Destructive Evaluation, ***2022, Sensors Journal, 202***

CUE
Centre for Ultrasonic Engineering

WAAM demonstrator with repair

- In process NDT to inform repair strategies in WAAM manufacture
- Aluminium alloy for ease of milling

1. Pre-repair NDT
2. Milling out defect regions
3. Redeposition WAAM
4. Post inspection

Contactless Inspection using Laser Ultrasonic Phased Arrays

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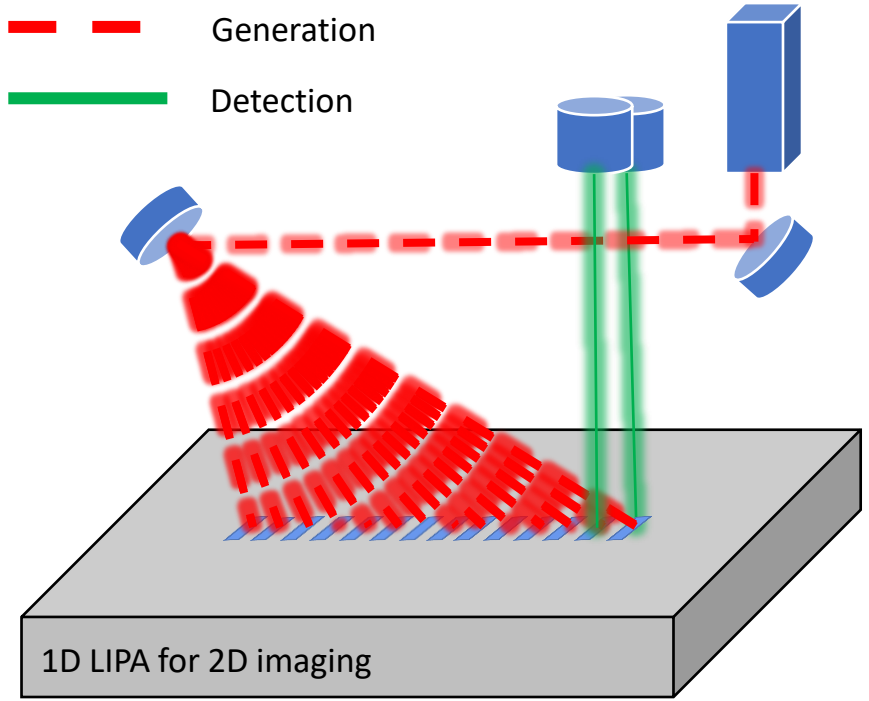
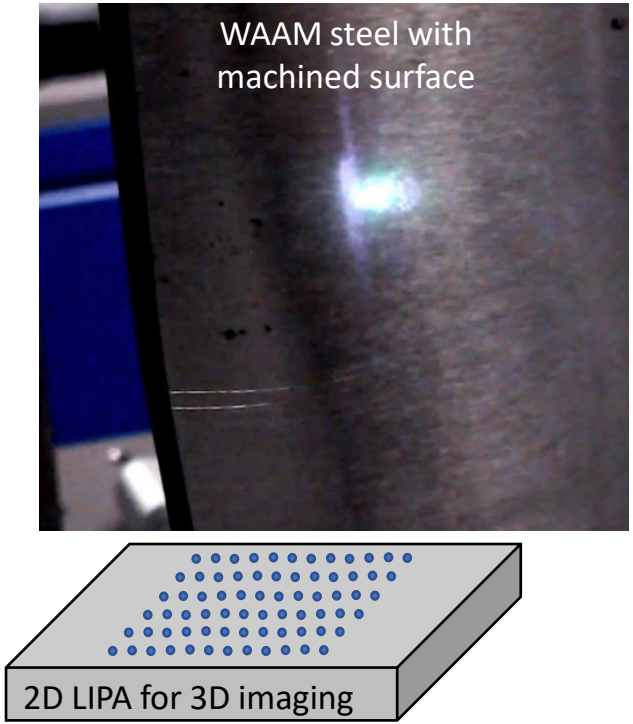
Laser Induced Phased Array (LIPA)

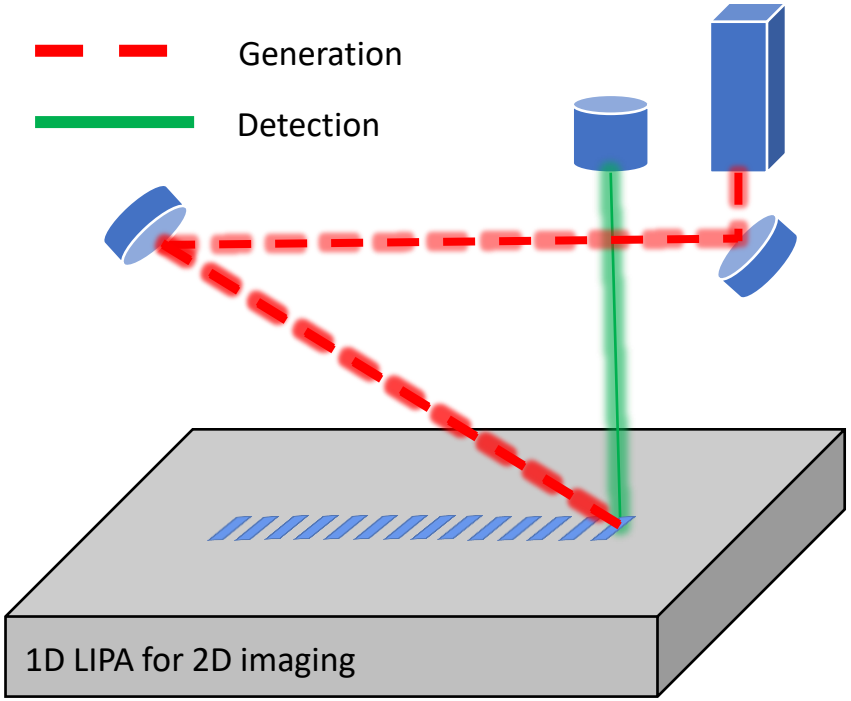
- High power laser generates elastic waves
- Detected using second laser probe beam
- High spatial and temporal resolution
- Non-contact
- Large stand off distances
- Can generate various wave modes, L, S, SAW and guided waves
- Ease of beam deflection lends to array methods FMC and TFM imaging



Theodosia Stratoudaki, email: t.stratoudaki@strath.ac.uk

Laser Induced Phased Array (LIPA)





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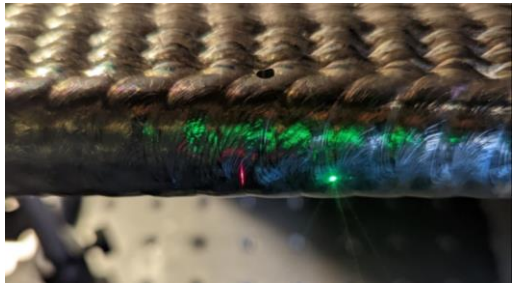
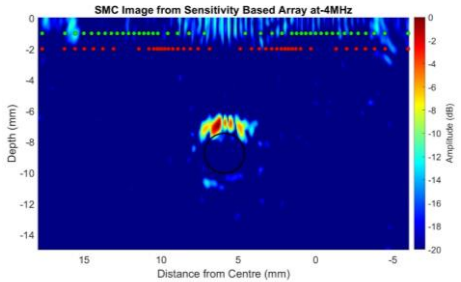
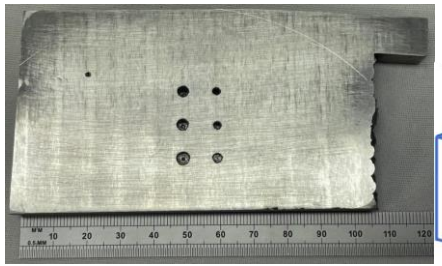
High resolution LIPA TFM imaging in AM samples

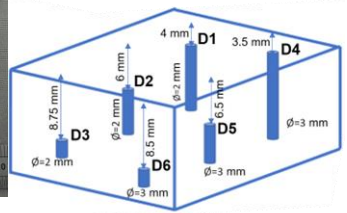
WAAM Ti-6Al-4V

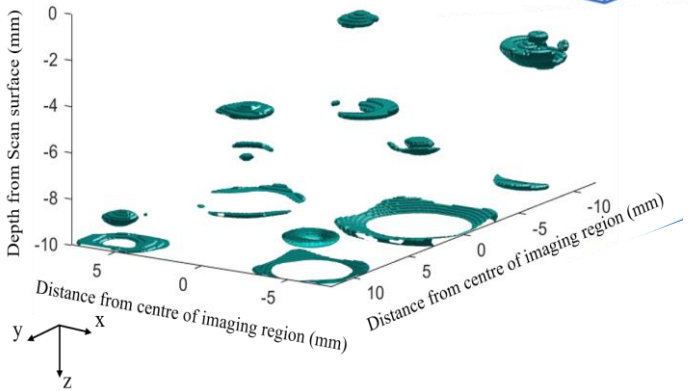




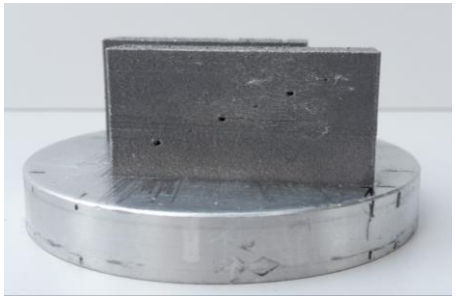
WAAM Steel – 3D imaging

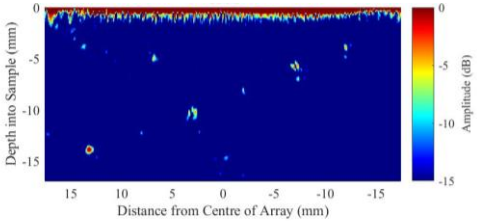






SLM Aluminium





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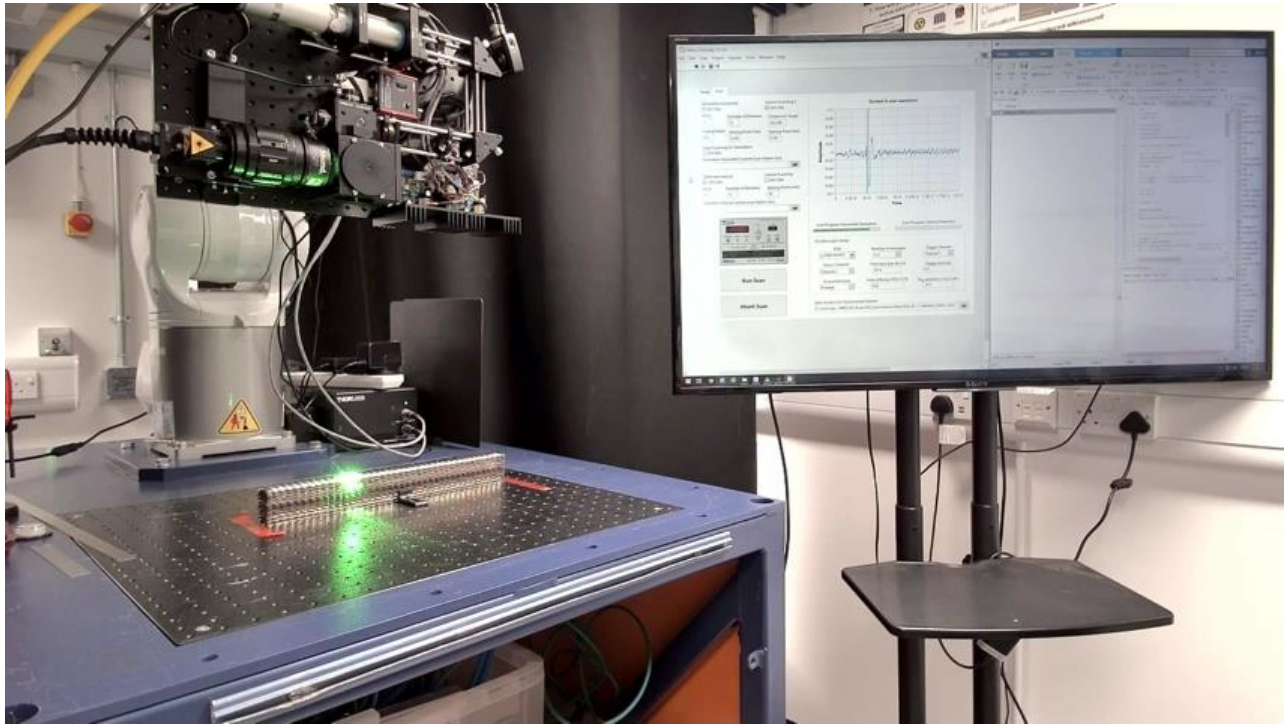
Robot deployment of LIPA



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Contactless Evaluation of Material Microstructure and Texture

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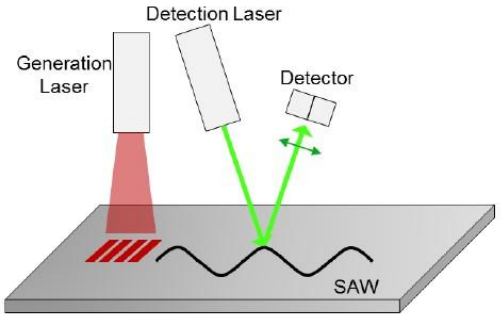
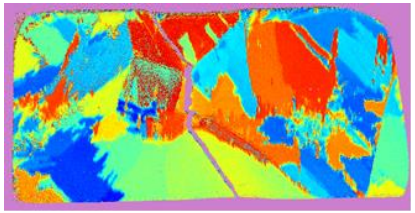
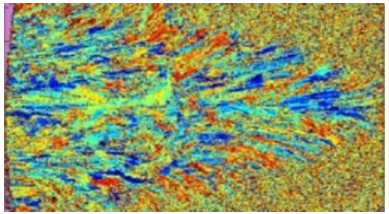
Spatially Resolved Acoustic Spectroscopy (SRAS) for microstructural imaging

- ✓ Maps the surface grain structure
  - Shape, size and orientation
- ✓ Wide variety of surface finishes
  - Any stage of manufacture
  - Flat or curved surfaces
- ✓ Titanium, Nickel, Steel, Aluminium and Silicon etc.

- ✓ Remote/Non-contact
  - laser generation & detection
- ✓ Simple operation
  - no vacuum chamber
  - no temperature requirements*
  - plug-n-play (when enclosed)
- ✓ Inexpensive
  - less than £100k parts+
  - commercial supplier available
- ✓ Unrestricted scan sizes
  - limited by mechanics
- ✓ High resolution
  - resolution of tens of microns
- ✓ Rapid scanning
  - Up to 10000 points/s (laser limited)

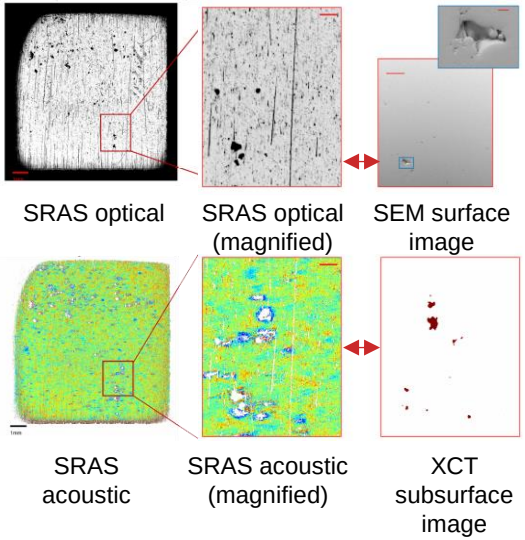






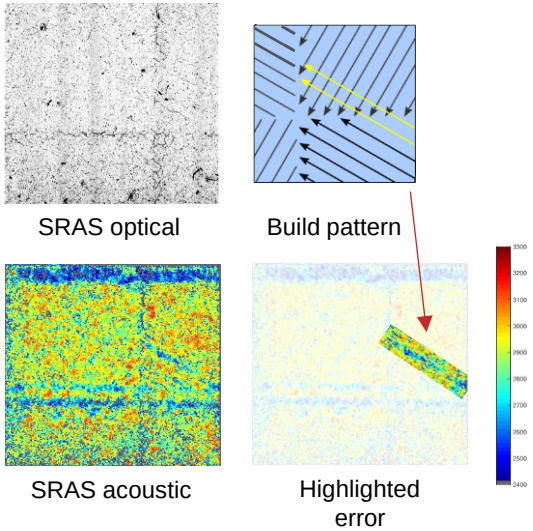
In-lab prepared AM sample imaging

Finding subsurface voids



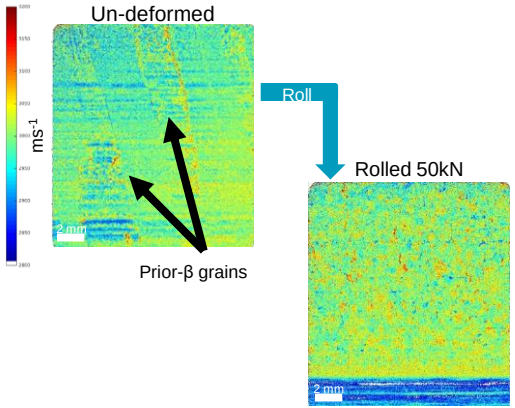
Spatially resolved acoustic spectroscopy for selective laser melting,
R. Smith, *Journal of Materials Processing Technology, 236* (2016).

Detecting build pattern errors



Meso-scale defect evaluation of selective laser melting using spatially resolved acoustic spectroscopy,
M. Hirsch, Proceedings of Royal Society A, 473, (2017).

Observing microstructure changes due to WAAM rolling forces



Side wall images on prepared Ti-6Al-4V WAAM samples

Spatially Resolved Acoustic Spectroscopy for Integrity Assessment in Wire-Arc Additive Manufacturing,
P. Dryburgh, *Additive Manufacturing, accepted* (2019).

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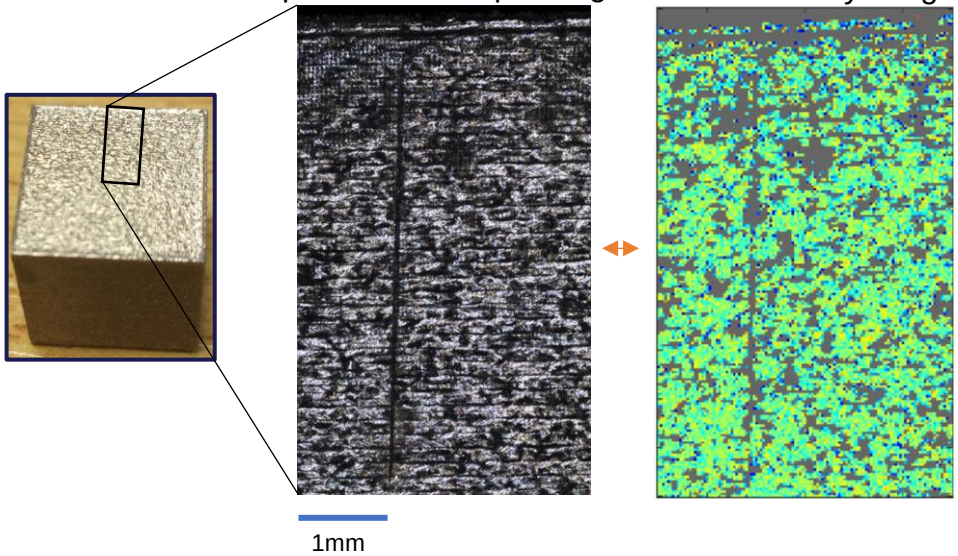
As-deposited sample scanning

1cm^3 Ti64 SLM cube (as-deposited)

Optical microscope image

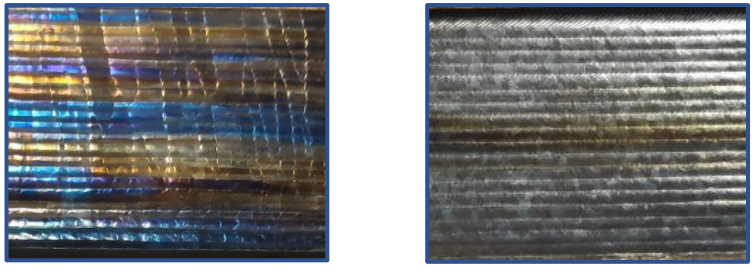
SRAS velocity image



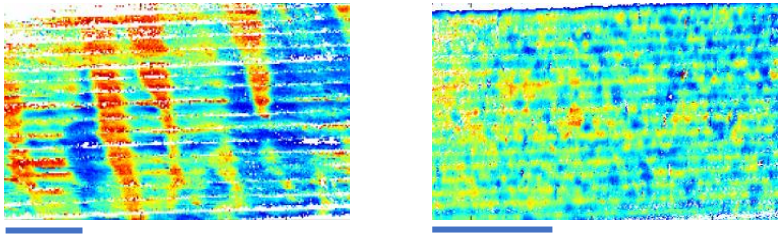
Imaging Material Texture of As-Deposited Selective Laser Melted Parts Using Spatially Resolved Acoustic Spectroscopy,"
R. Patel, Applied Sciences, vol. 8, p. 1991 (2018).

Wire-Arc-Additive-Manufacturing Ti64 Samples

Optical microscope images



SRAS velocity images



'Spatially resolved acoustic spectroscopy for integrity assessment in wire–arc additive manufacturing',
P. Dryburgh, *Additive Manufacturing*, vol. 28, pp. 236–251, Aug. 2019

Summary

- RCNDE is a well-established partnership between industry and academic researchers
- Research is driven by the needs of industry
- Several developments have relevance to Additive Manufacturing
  - Non-contact inspection
  - As-prepared surfaces
  - Capable of being integrated with manufacturing equipment

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