Advances in Laser Welding, Non-Destructive Testing and 3D Printing at TWI

TWI Seminar

**Jidosha Kaikan, Ichigaya,
Kudan Minami 4-8-13, Chiyoda-ku,
Tokyo, 102-0074**

25 November 2015

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Advances in Laser Welding, Non-Destructive Testing and 3D Printing at TWI

Jidosha Kaikan, Ichigaya, Kudan Minami 4-8-13, Chiyoda-ku, Tokyo, 102-0074
Tel: 03-3264-4719

25 November 2015

09.45	Registration	
10.00	Welcome and Introduction	UK Dodwell
10.05	What's new at TWI	Fred Delany
10.30	Additive Manufacturing using Selective Laser Melting (SLM) and Electron Beam Melting (EBM)	Jon Blackburn
11.00	Next Generation Ultrasonic Inspection	Dimos Liaptsis
11.30	*Coffee break and FMC/ TFM demonstration*	
11.45	Laser Welding of dissimilar Cu and Al joints	Jon Blackburn
12.05	Development of automated inspection system for components with complex geometry	Dimos Liaptsis
12.25	Discussion	
12.40	*Lunch*	

Speakers will be:

Jon Blackburn

Jon Blackburn is a Group Manager at TWI, where his responsibilities include managing TWI's laser welding activities. He joined TWI in 2006 as a Research Engineer, and since then has been working in the development and application of laser processes for TWI's Industrial Members in primarily the aerospace, automotive, defence and rail sectors. Within TWI's Joining Group, he also has close interaction with TWI's electron beam and friction processing activities.

Dimos Liaptsis

Dimos Liaptsis is a Principal Project Leader within the Advanced Non-Destructive Testing group with 12 years' experience in research and development of advanced and bespoke ultrasonic testing techniques within a range of engineering sectors. He joined TWI in 2007 and is responsible for TWI Wales NDT research activities in advanced ultrasonic testing at Port Talbot, South Wales. The centre services members across the full range of industry sectors supported by TWI and supports many of the other technology groups operating throughout the organisation'.

Fred Delany

Fred joined the NDT research department of TWI in 1986, after obtaining a degree in mechanical engineering and an MSc in offshore structures.

Fred has held a number of senior business development and commercial roles, and contributed to the development of TWI outside the UK. He is currently managing the development of TWI R&D activities in Asia, and visits Japan 4 times per annum.

What's New at TWI

Fred Delany

Materials Joining and Engineering Technologies

Introduction

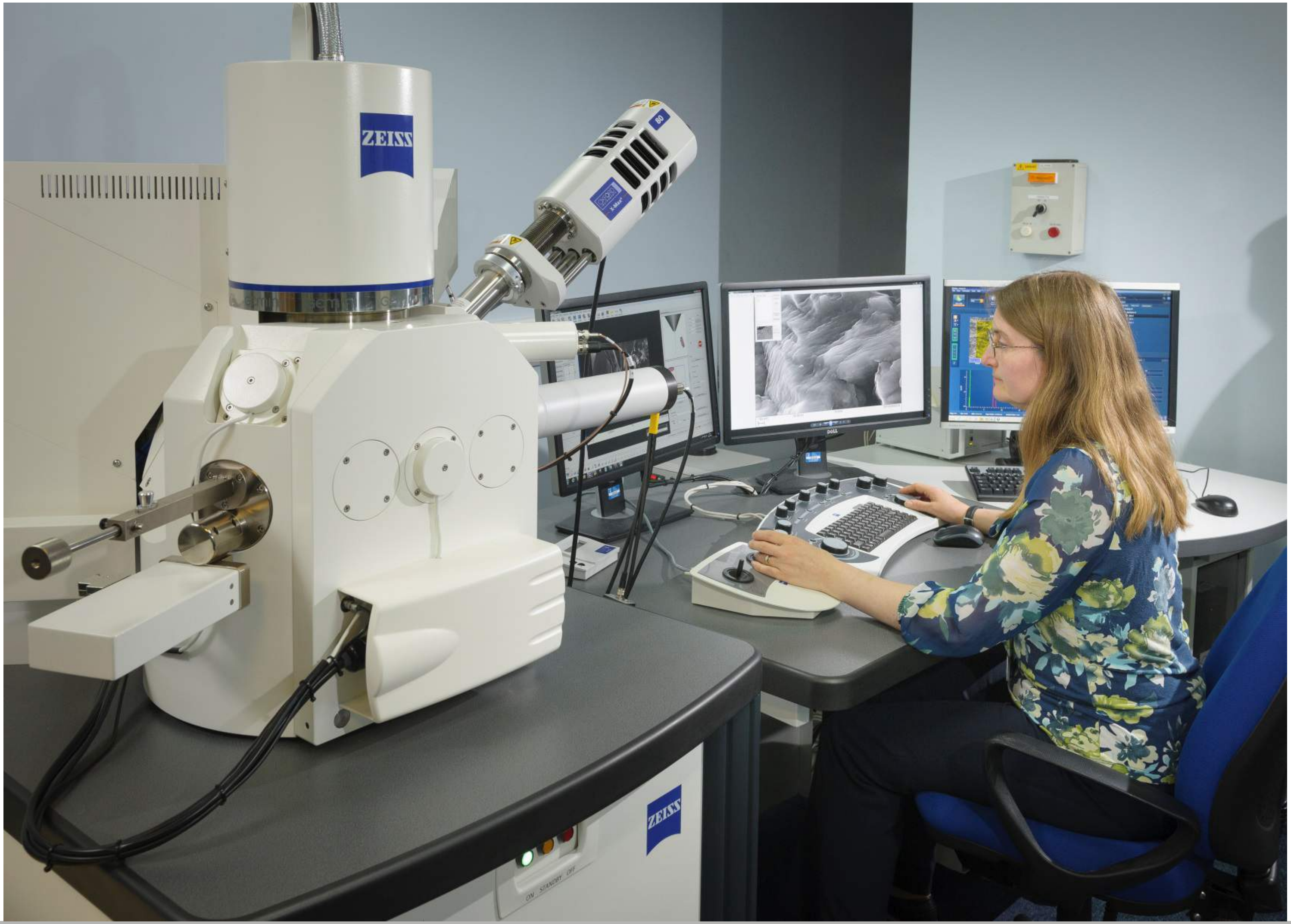
- TWI has benefitted from £15 Million investment in new equipment and facilities in 2015.
- Facilities can be divided into:

- New materials analysis equipment.
- New mechanical testing facilities.
- New fabrication technologies.
- New QA and inspection techniques.

Materials Analysis Equipment

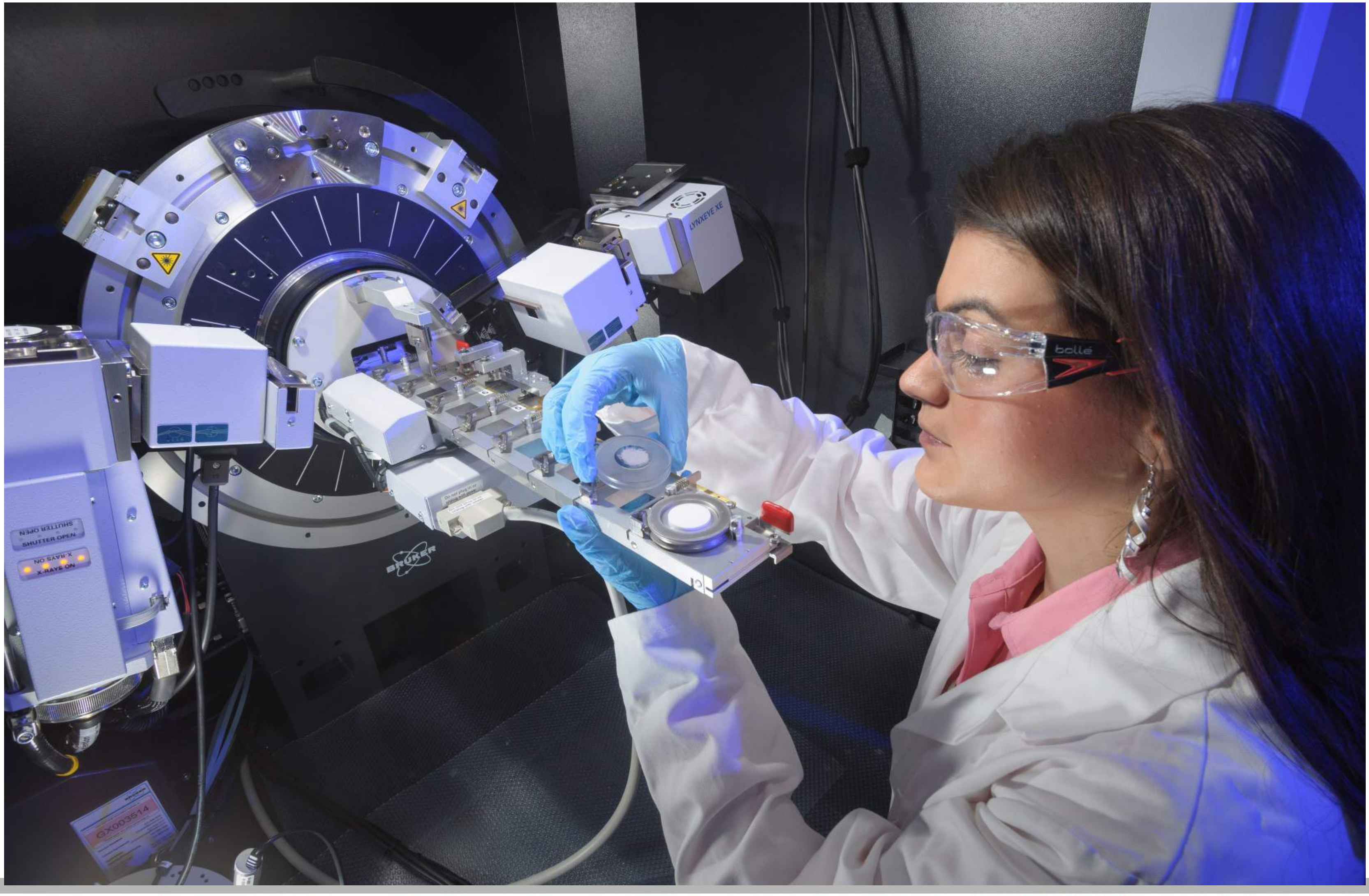
Materials Joining and Engineering Technologies

New SEM Facility



X-Ray Diffraction Spectrometer

X-Ray Diffraction Spectrometer

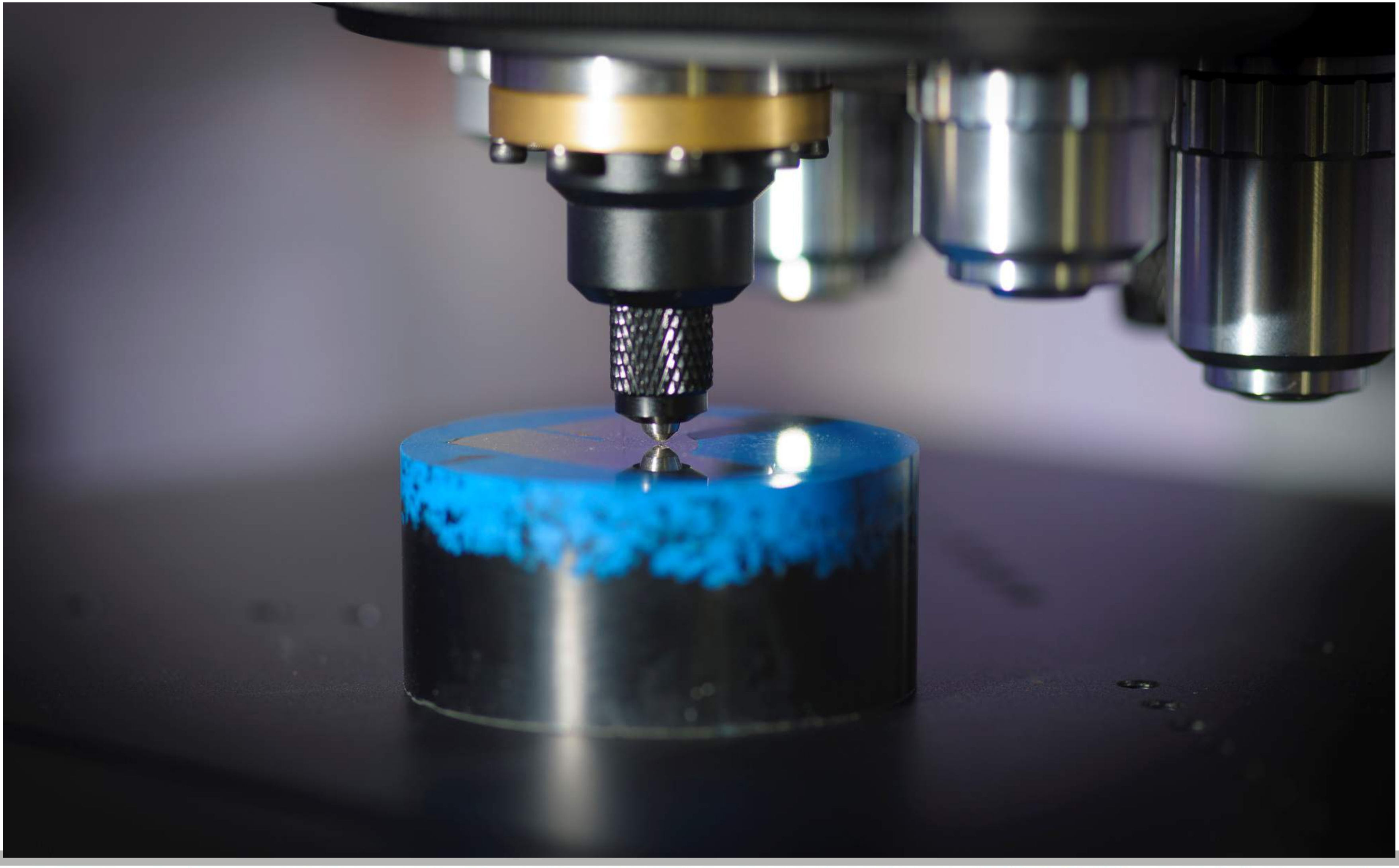


X-Ray Diffraction Spectrometer

- Can be used for analysis of metals, polymers and corrosion products
- Shows the crystalline phase of corrosion products
- Shows the spacing of molecular chains in a polymer – evidence of ageing
- Shows the distribution of inorganic crystalline particulates in a polymer continuum

Automated Hardness Testing

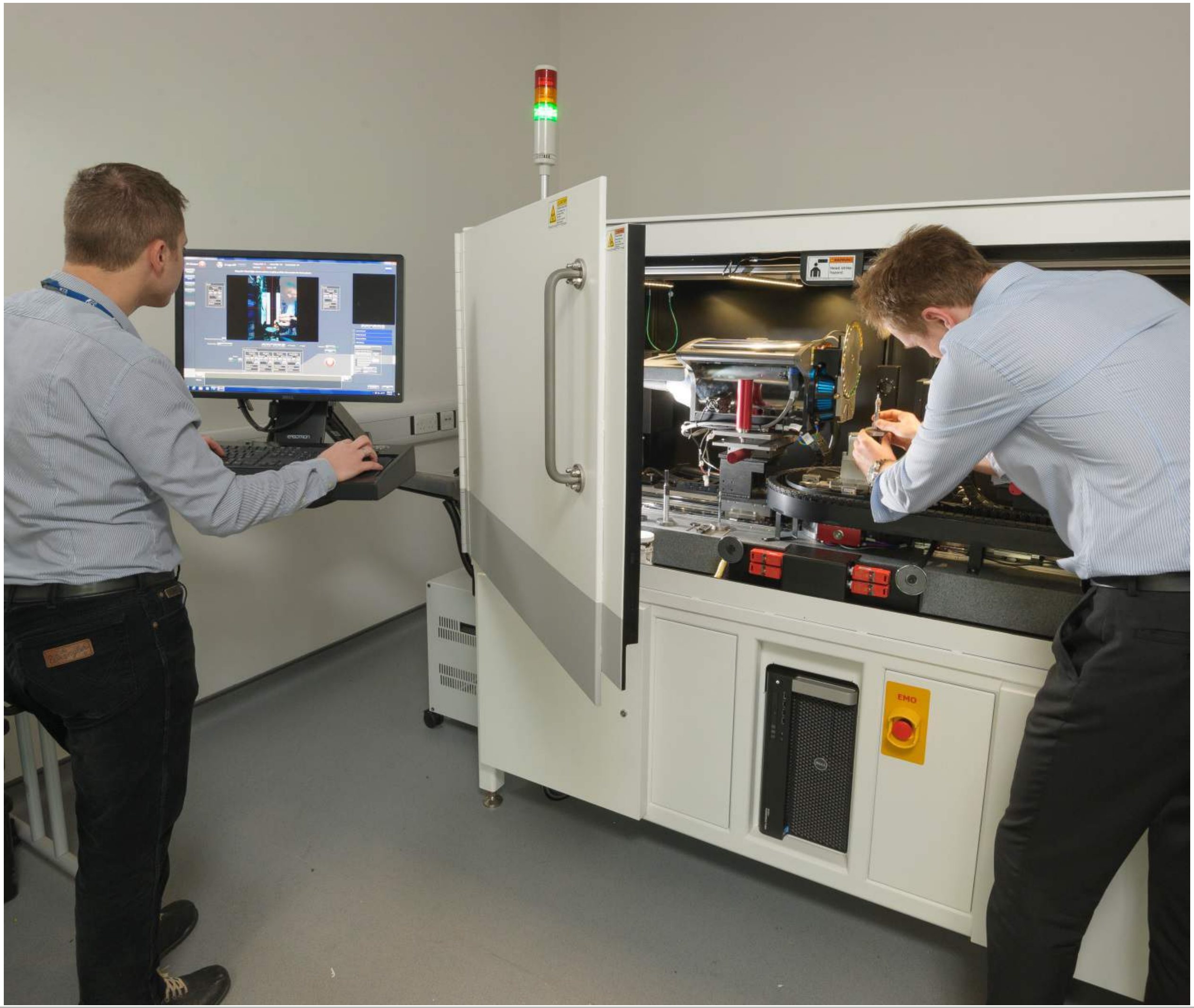
Automated Hardness Testing



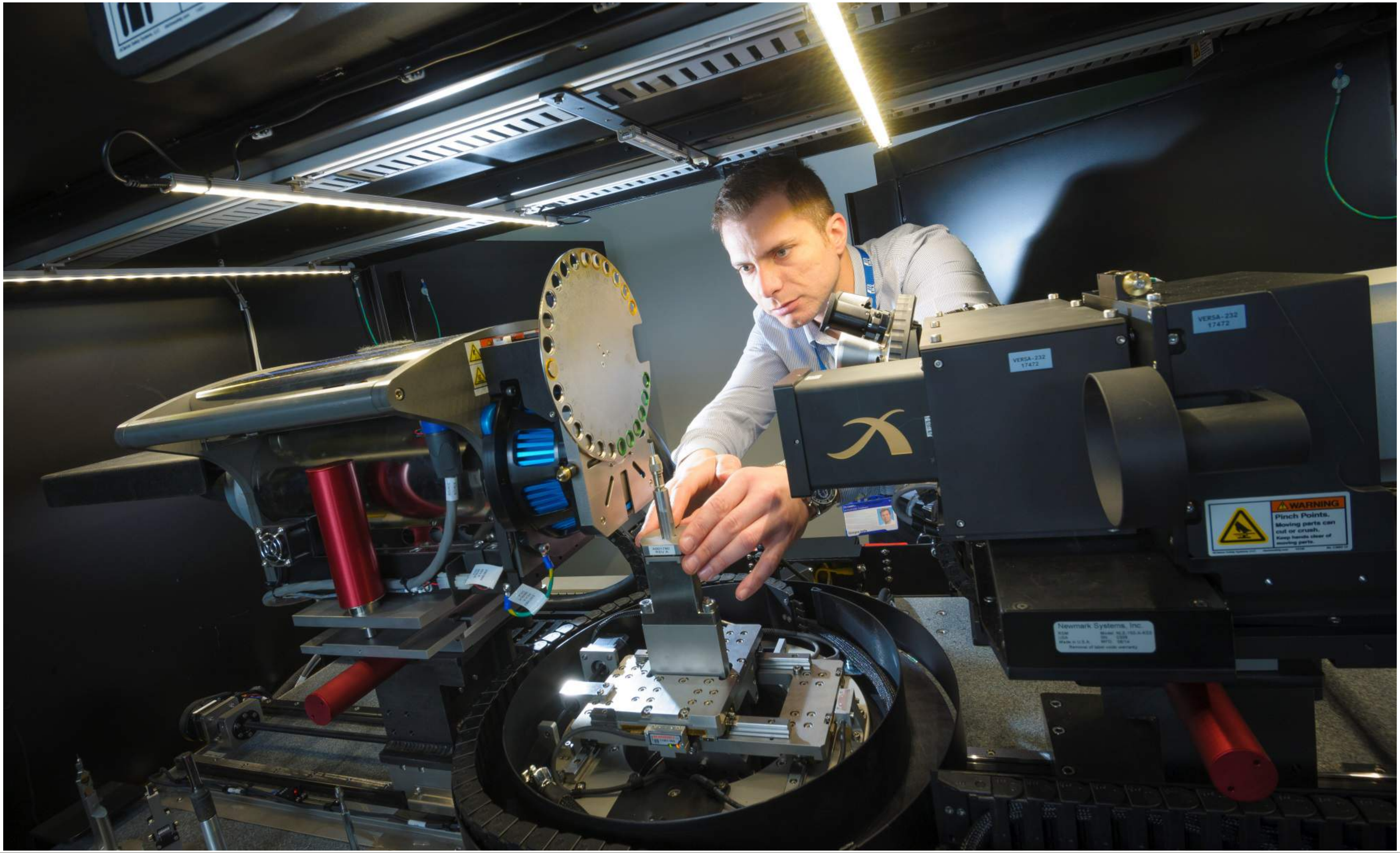
Optical Microscope linked to WebEx

X-Ray Microscope

X-Ray Microscope



X-Ray Microscope



New Mechanical Testing and Sample Preparation Facilities

Materials Joining and Engineering Technologies

1000kN Servo-Hydraulic Fatigue Machine

100KN universal testing machine

600KN universal testing machine

New impact testing machine

Automated Charpy Testing from -180C to +600C

Universal testing of micro-scale components

CNC machining centre

Wire eroding machine

Large Band Saw

New Fabrication Technologies

Materials Joining and Engineering Technologies

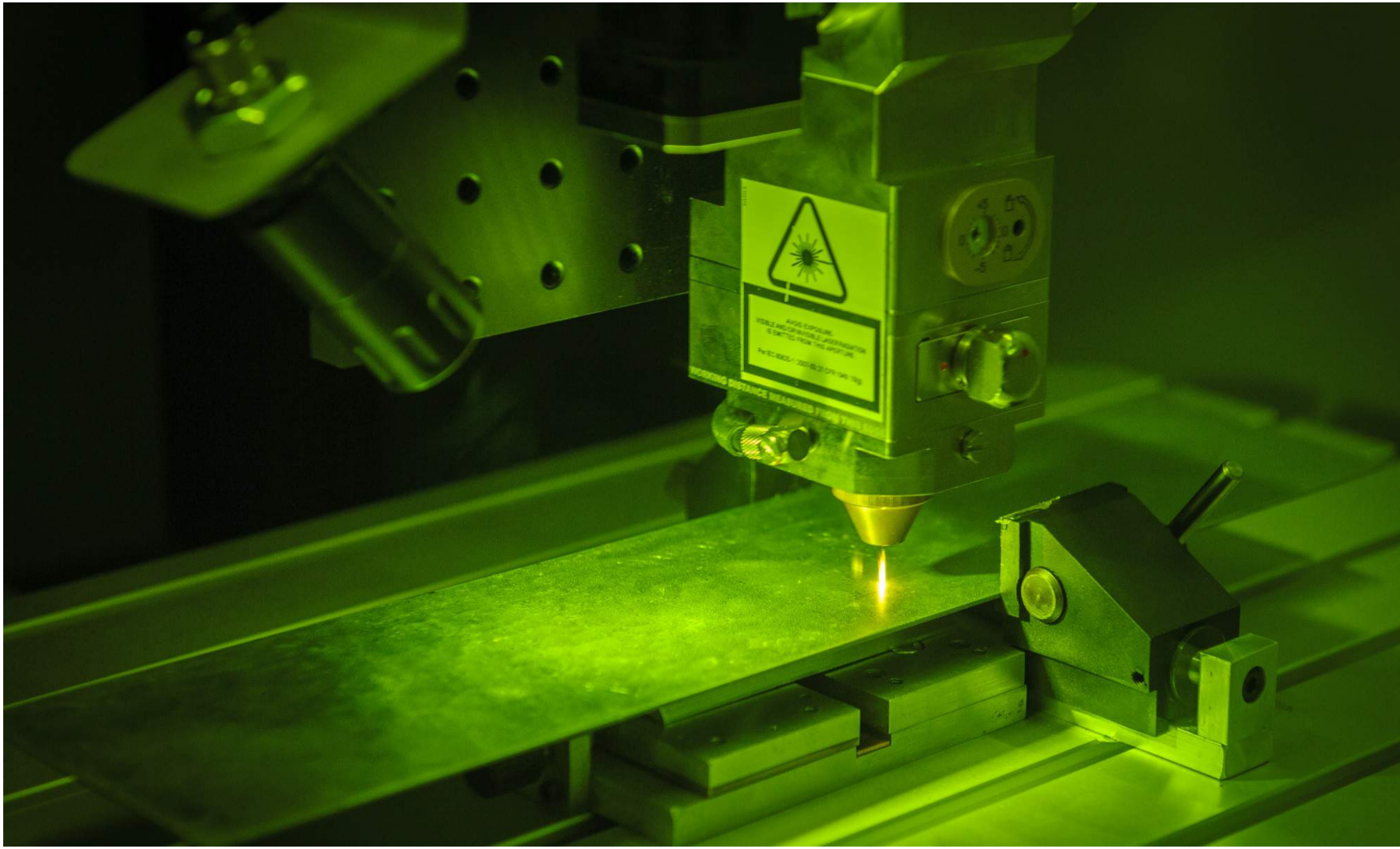
Hot Wire TIG

Hot Wire TIG

10kW and 5kW Ytterbium Fibre Lasers

Pulsed Laser System (QCW)

Pulsed Laser System (QCW)



100kW EBW - Installation

60kV EB Machine for Surface Modification

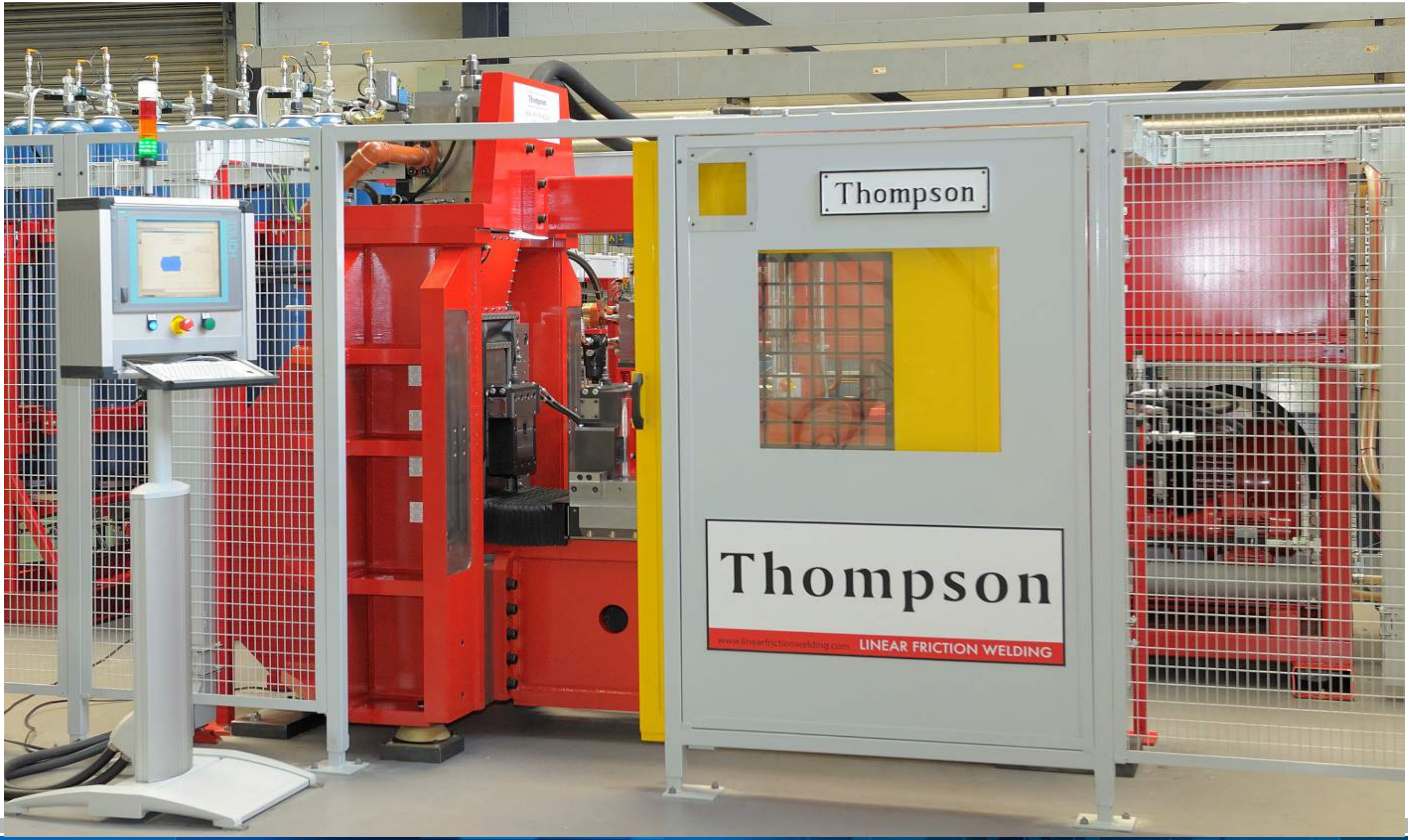
AWEA FSW Machine

AWEA FSW Machine

- 4m x 3m gantry
- 1m Z axis
- Capable of welding 6-8mm Al (6xxx series)
- High precision positioning and repeatability

Friction Stir Spot Welding Machine with re-fill capabilities

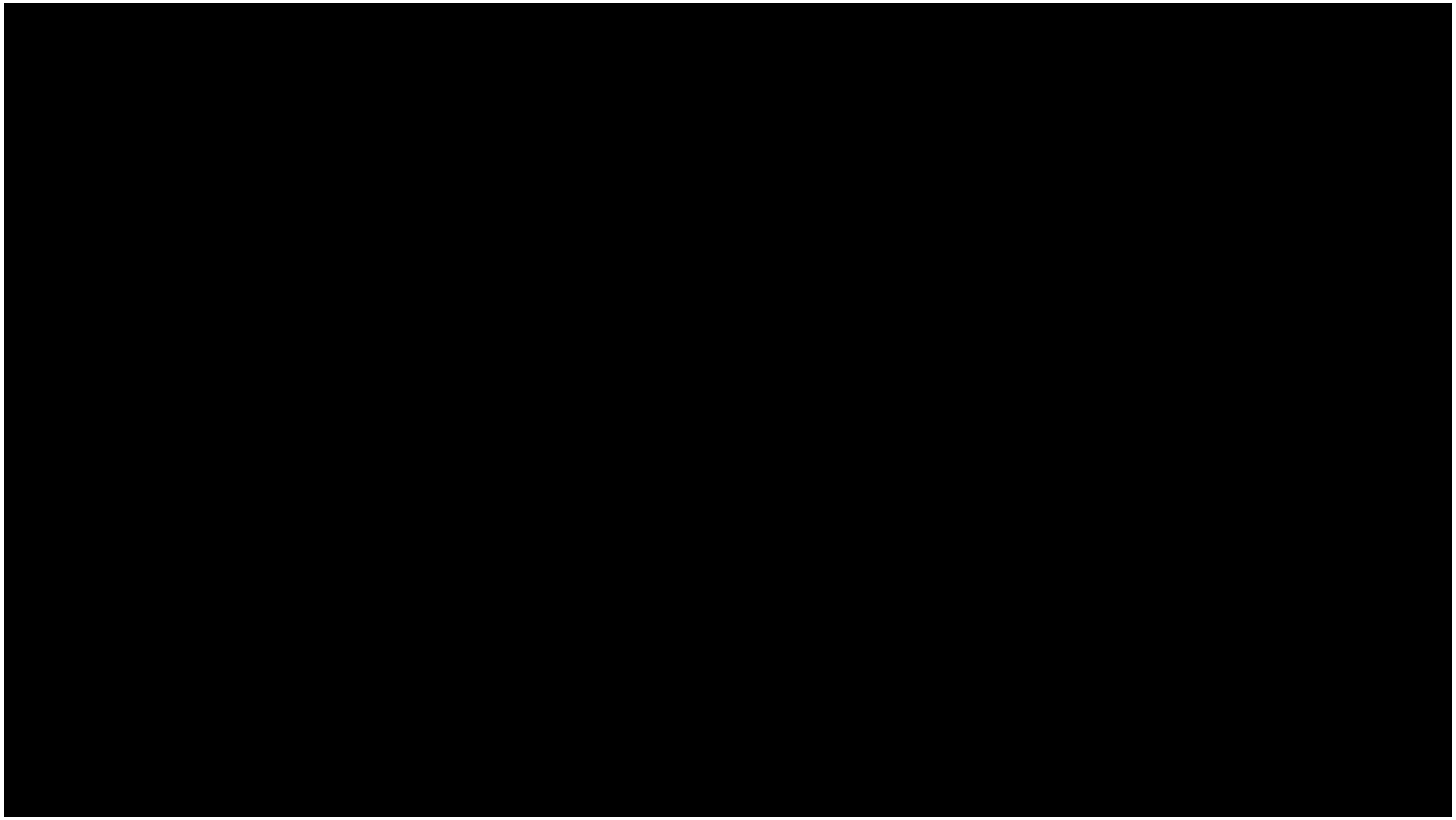
Linear Friction Welding machine



Our involvement in Friction Welding

TWI's FlexiFab Robotic FSW System

Flexifab video



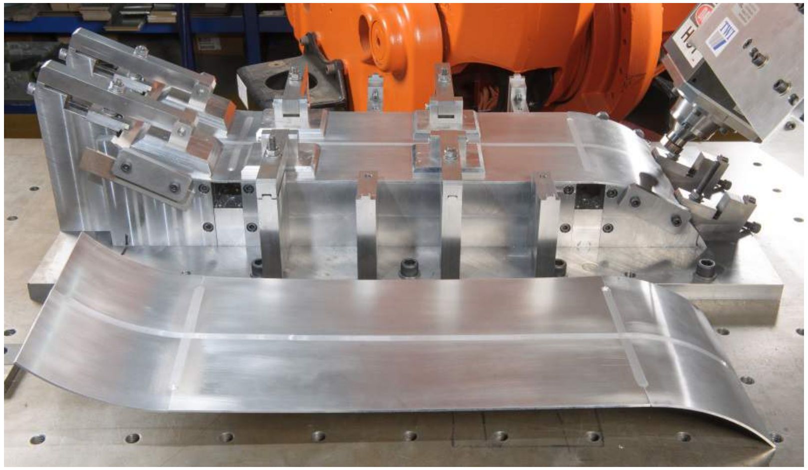
TWI's FlexiFab Robotic FSW System

System specifications

- Rotation speed:3300rpm
- Spindle torque:70Nm
- Axial Force:10kN
- Welding speed:>2m/min
- Retractable pin
- Turntable for circumferential welds

Four different FSW techniques

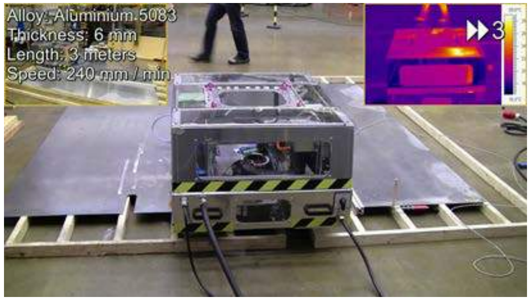
- Conventional FSW
- Floating bobbin FSW
- Stationary shoulder FSW
- Corner FSW



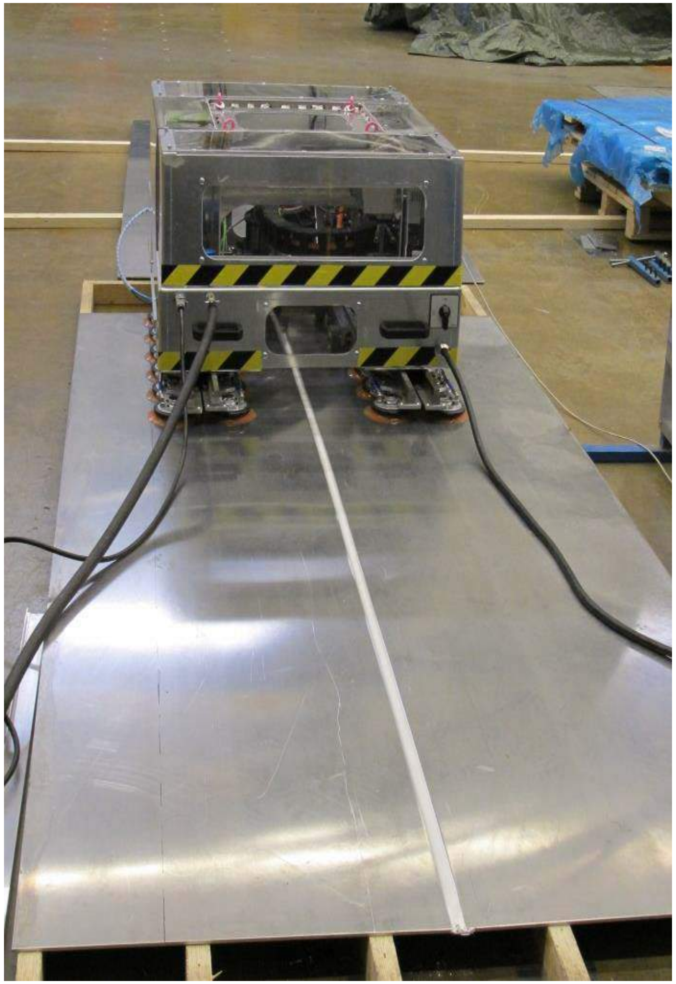
Mobile FSW System (Mobi-Weld)

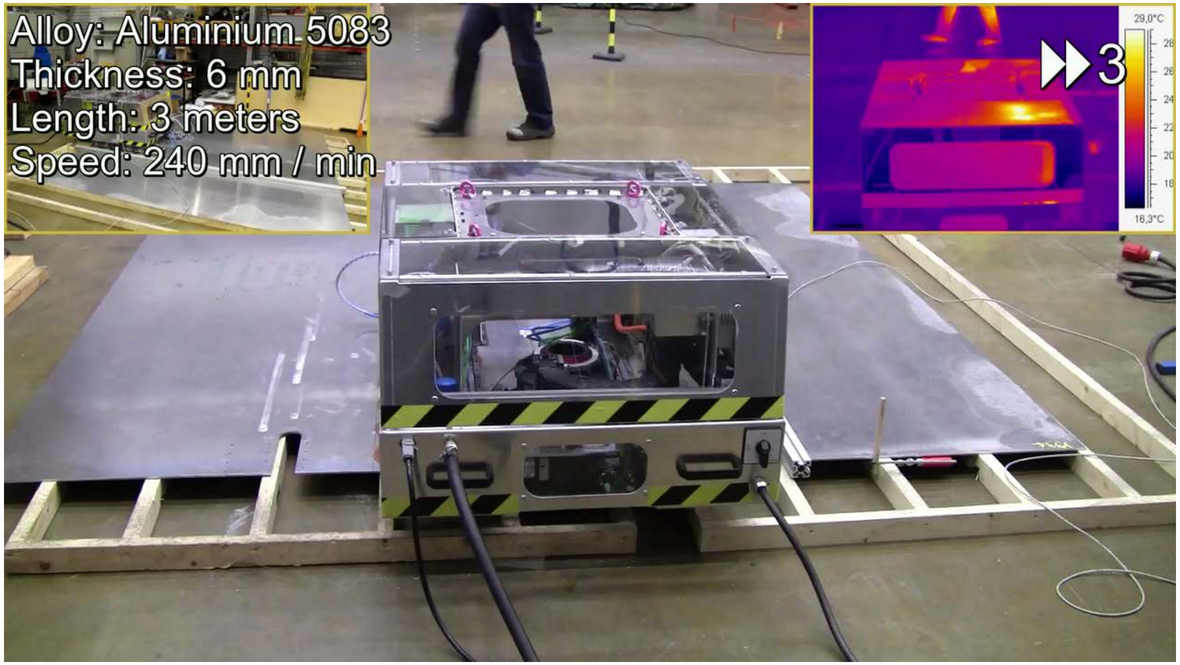
- Unlimited continuous motion through sequencing of a walking mechanism with integral vacuum cups which provide the reaction against the welding forces.

- Seam tracking capability to align the tool to the plate interface



Video

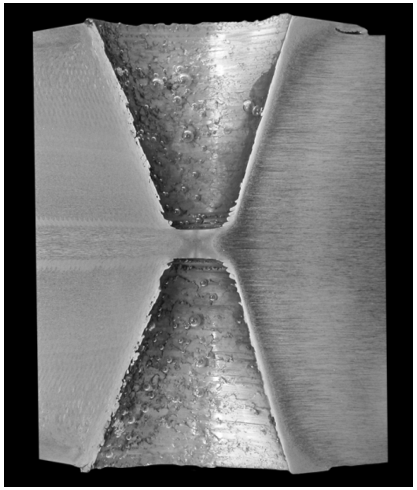


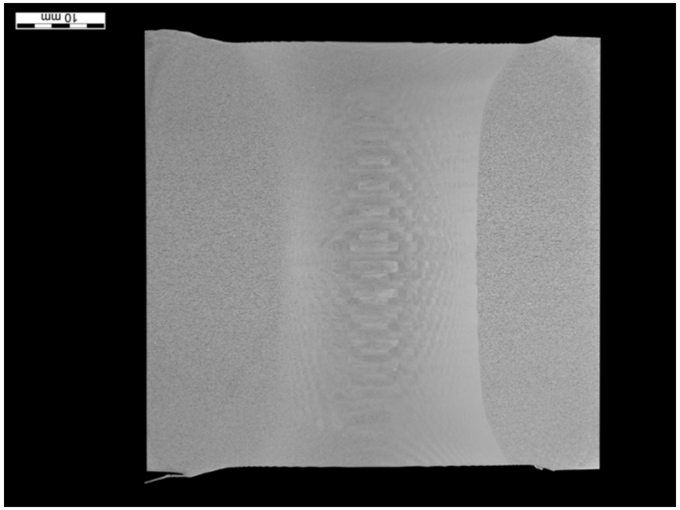


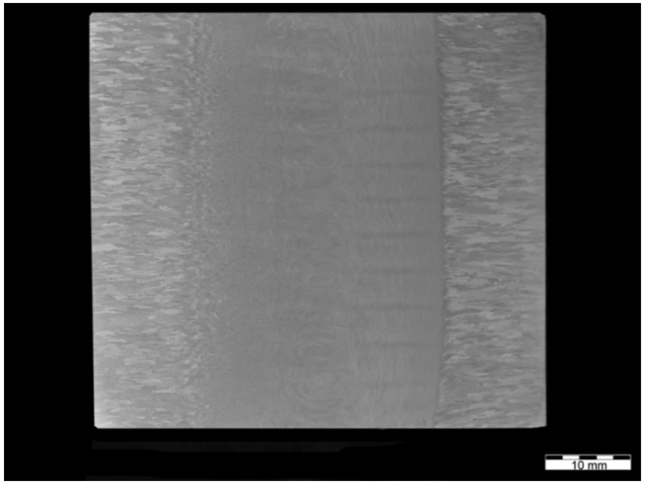
Alloy: Aluminium 5083
Thickness: 6 mm
Length: 3 meters
Speed: 240 mm / min

Thick Section FSW

Novel FSW techniques to minimise cost, production cycles and weld heat input compared to fusion and the weld /flip/ weld FSW technique







Commercial Cold Spray Systems (2014)

CGT Kinetiks® 4000/47

Sulzer Metco Kinetiks® 8000/52

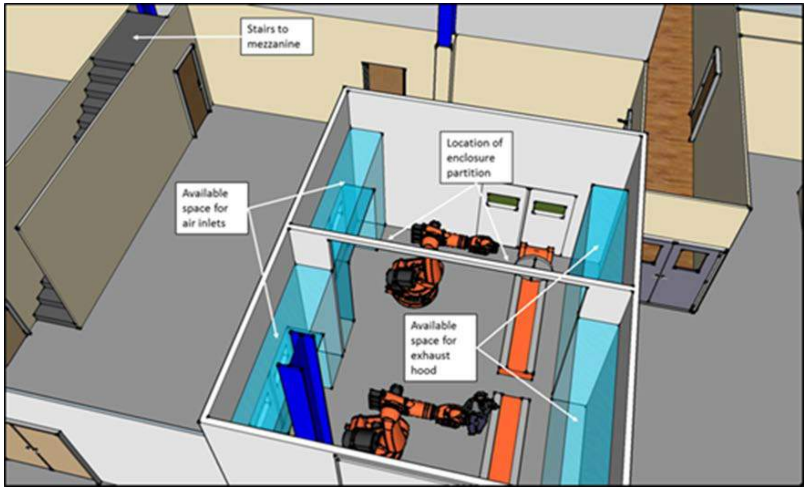
Plasma Giken PCS-1000

Impact Innovations 5/11

Impact Innovations 5/11 Cold Spray Gun

TWI Large-Scale Spray Booth

- Offline programming of surface preparation + coating process using 3D simulation software & CAD models.
- Translation to actual coating of medium-to-large components.
- New cold spray system



Cold Spray Booth

Inspection and Materials Qualification Testing

Materials Joining and Engineering Technologies

6 axis UT Immersion Tank

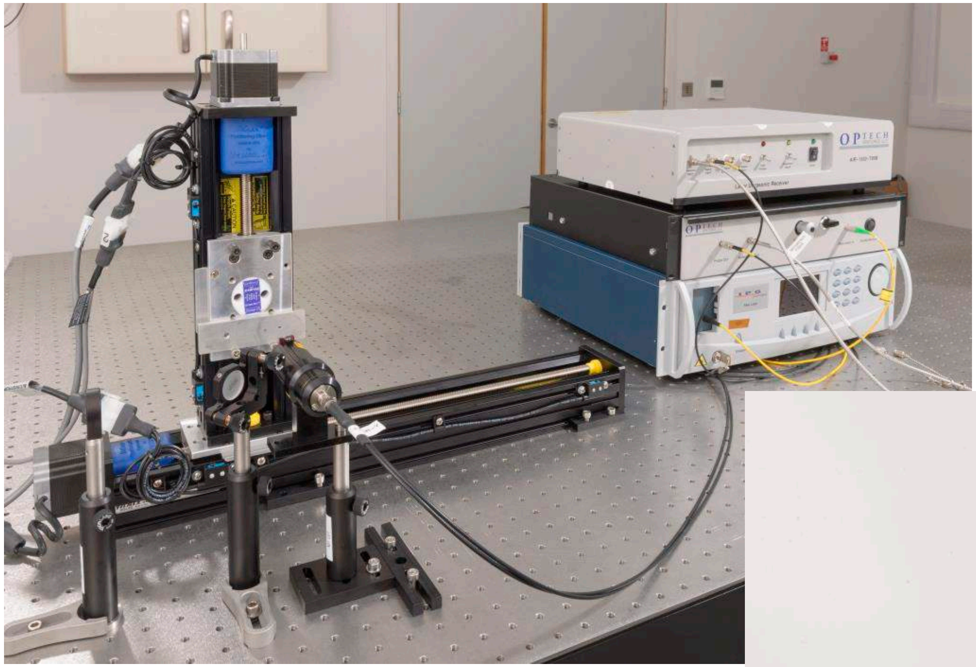
6 axis UT Immersion Tank

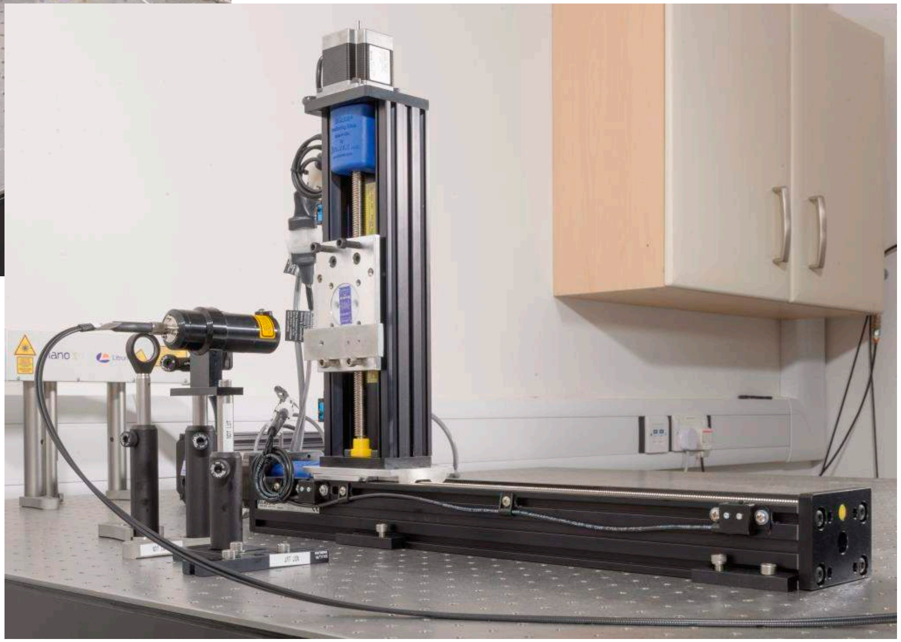
Electro-Magnetic Acoustic Transducers - EMATS

Innerspec Power Box H

Custom rack-mounted research system

Laser UT Equipment





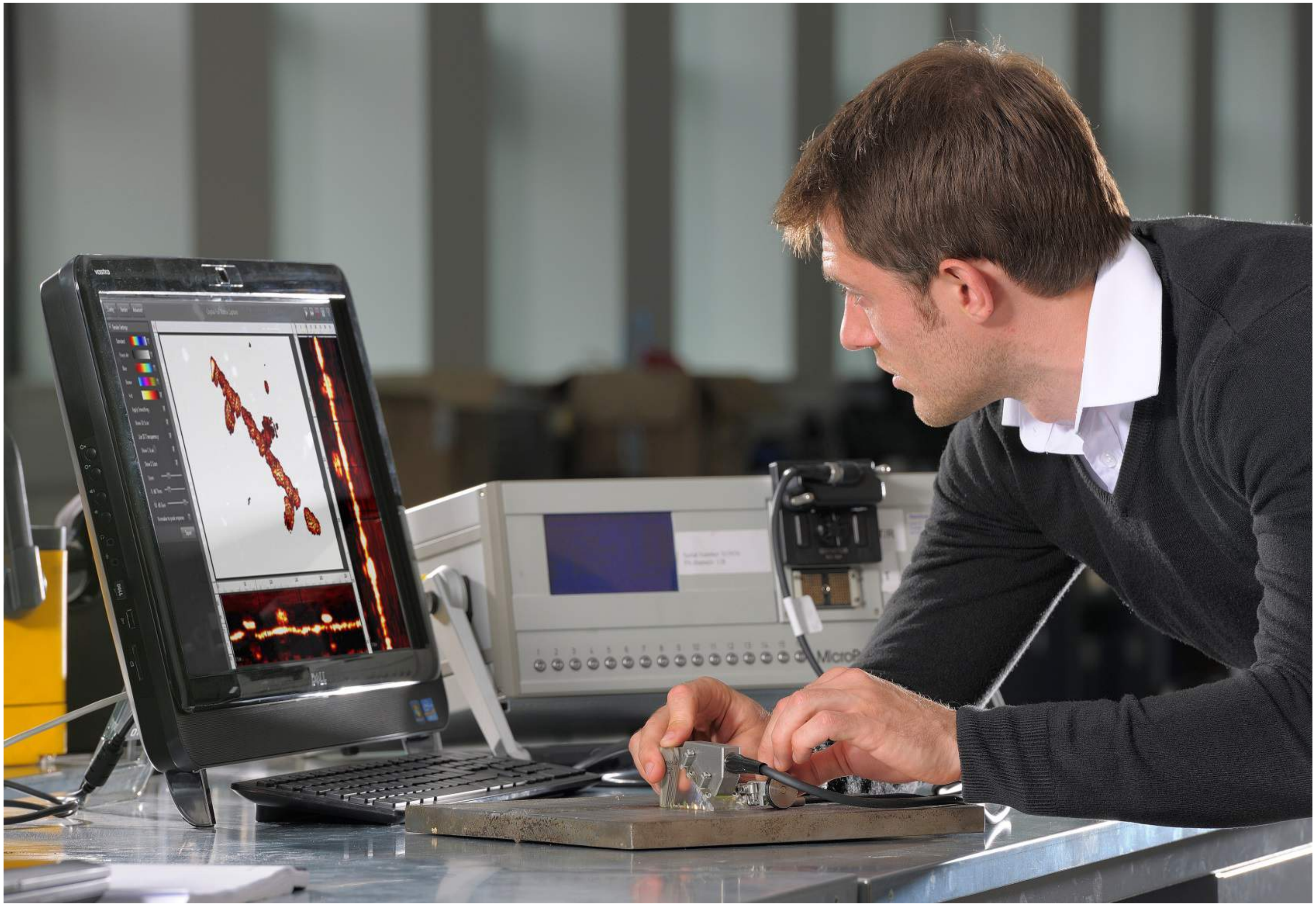
Eddy Current Arrays– Eddyfi Ectane

128 channels. Wide range of displays.

Capability for different probe configurations (Absolute, T/R …) within an array

Tube Inspection capabilities, ECT (multi coil / multi-frequency), RFT, NFT, MFL

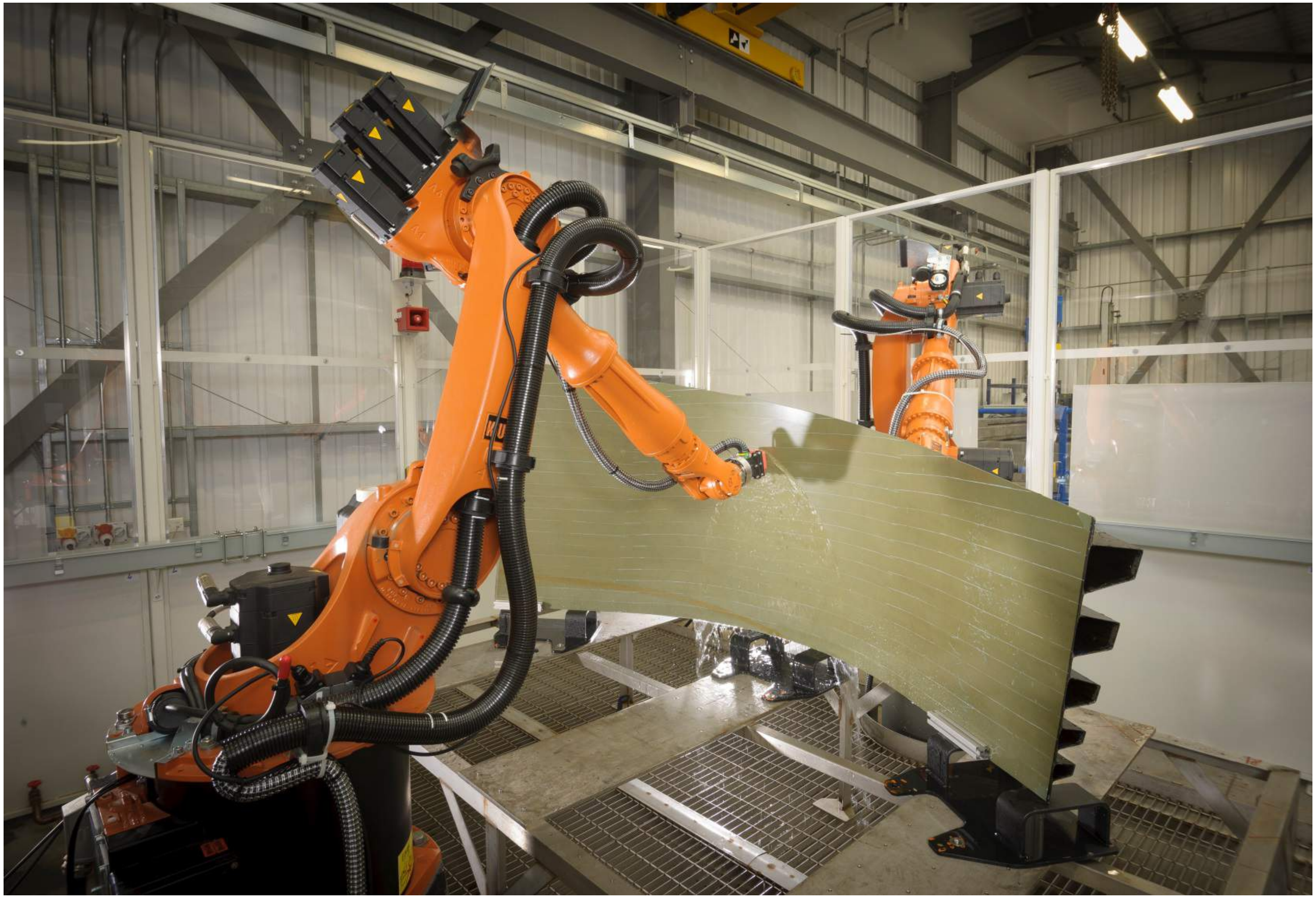
Phased Array UT Full Matrix Capture



Digital Radiography

Digital Radiography

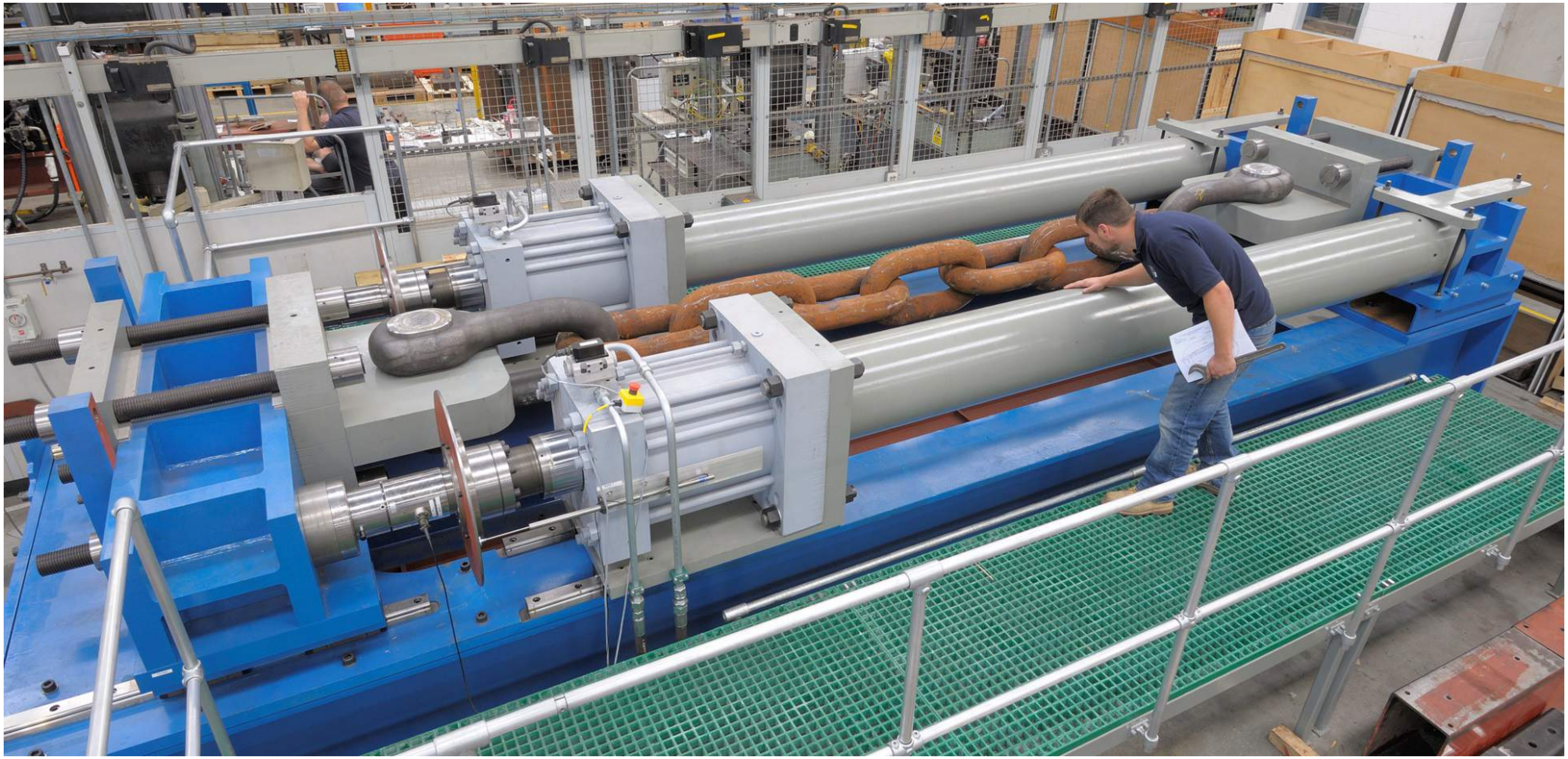
Inspection of Composite Panels



Inspection of Composite Panels

Robotic Inspection of Fan Blades

Full Scale Chain Testing Facility



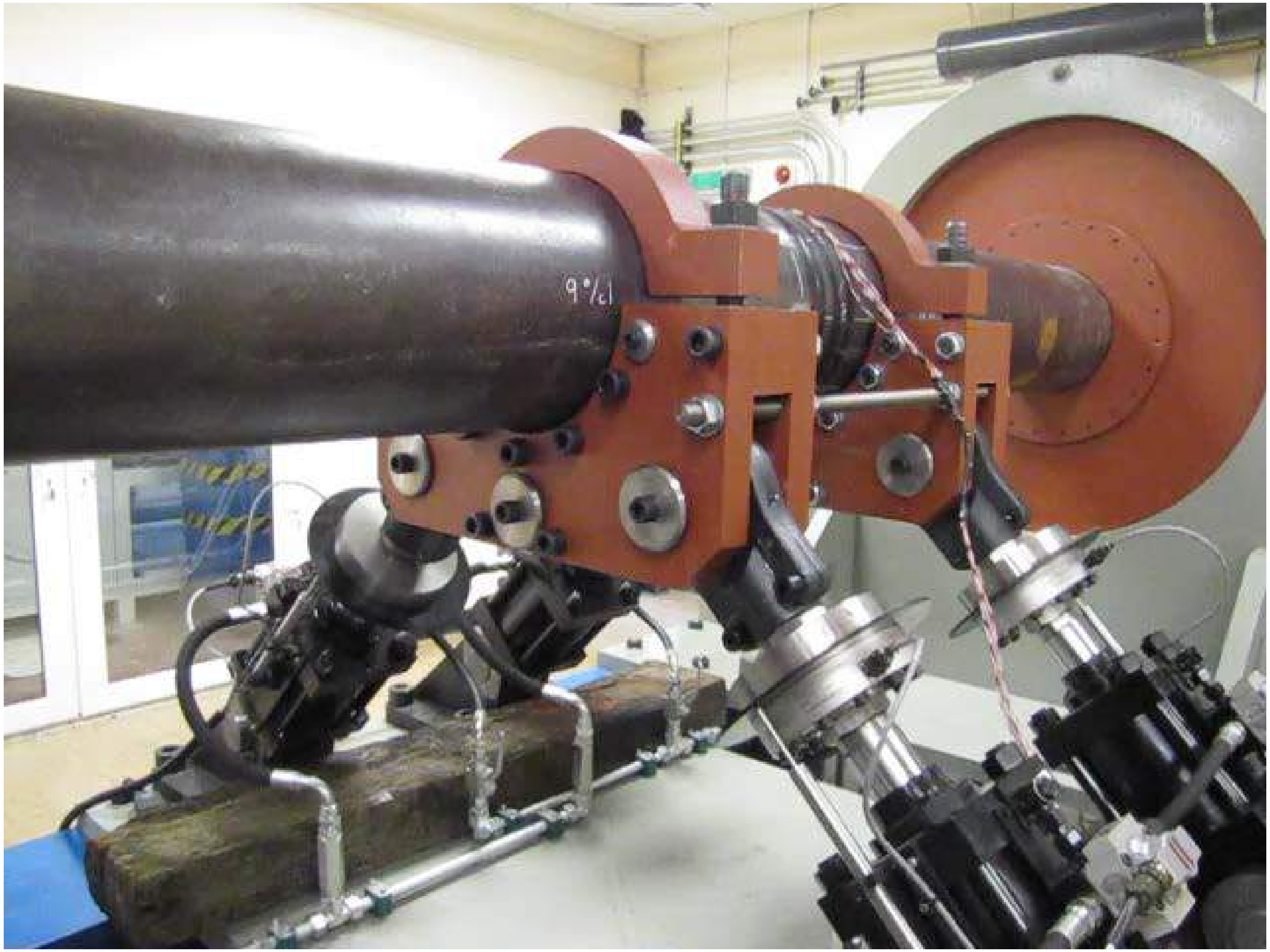
Full Scale Chain Testing Facility

Chain Testing Facility

Chain Test in Sea Water

Large Scale Environmental Testing

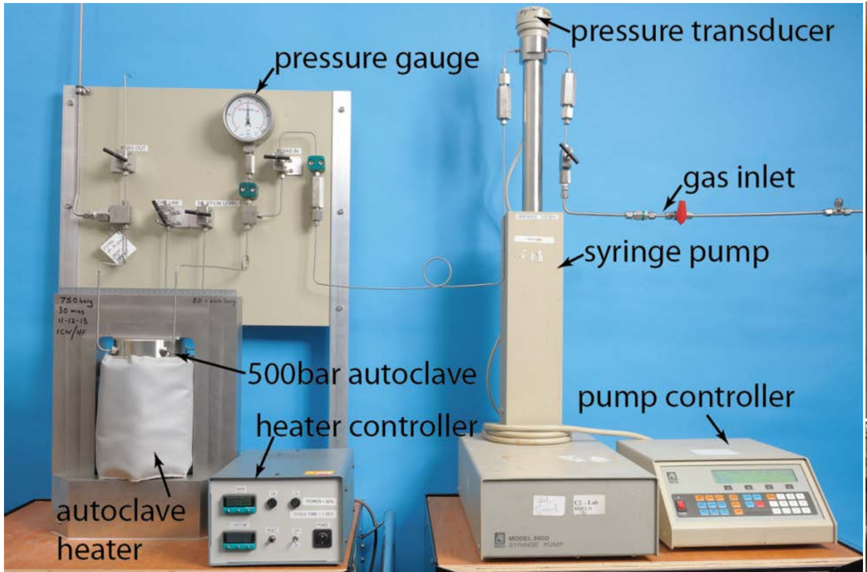
Full Scale Corrosion Fatigue Test of pipelines

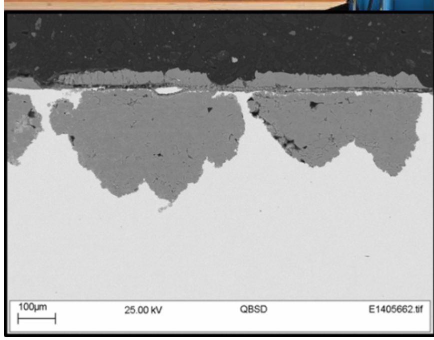


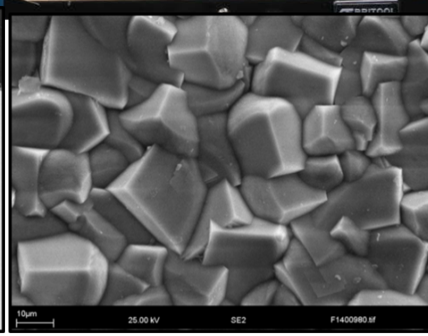
High Pressure High Temperature Corrosion Fatigue Testing

Flow loop - exposure of polymer-lined pipe to solvent-sour gas mixtures at temperature and pressure

Hot Topics - Materials Performance in Aggressive Environments (HPHT)



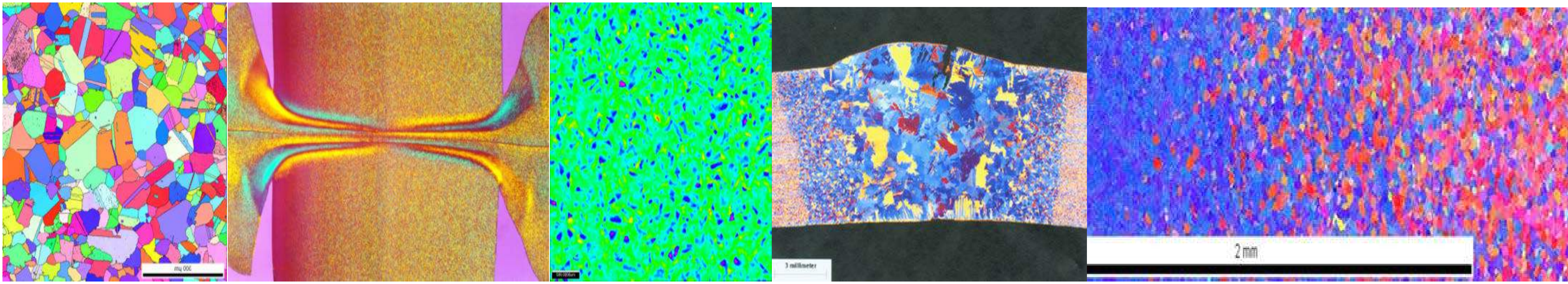




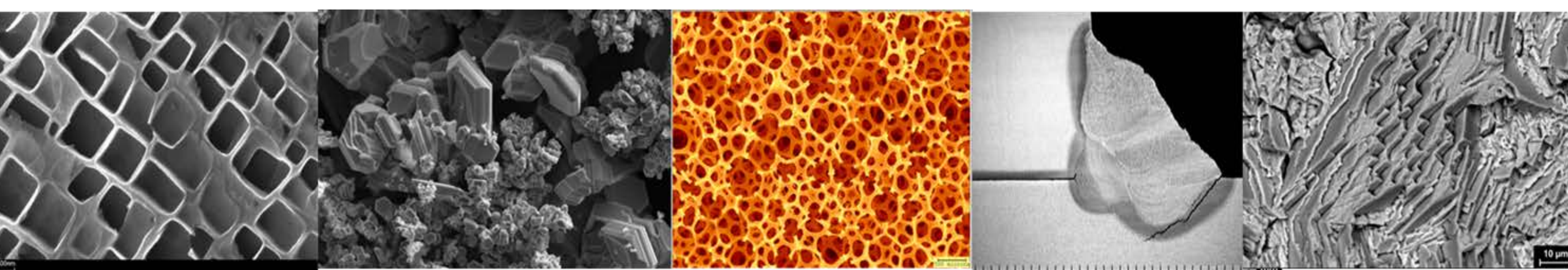
HPHT corrosion, up to 1000 Bar (static)

HPHT corrosion fatigue (dynamic)

HPHT permeation, ageing and RGD testing of polymers



Thank you



Additive Manufacturing using Selective Laser Melting (SLM and) Electron Beam Melting (EBM)

Dr Jon Blackburn

Materials Joining and Engineering Technologies

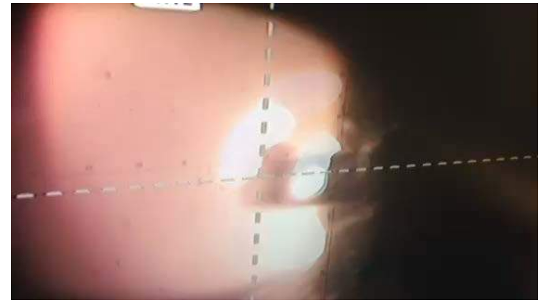
Overview

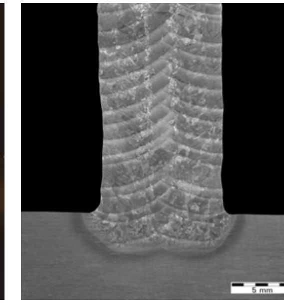
- TWI's Additive Manufacturing activities
- Selective Laser Melting (SLM)
  - Technology overview
  - SLM development work-flow
  - Current Projects
  - Case Studies
- Electron Beam Melting (EBM)
  - EBM equipment development
  - EBM QA probe
  - Case Study – Turbocharger assemblies
- Laser Additive Manufacturing JIP
- Summary

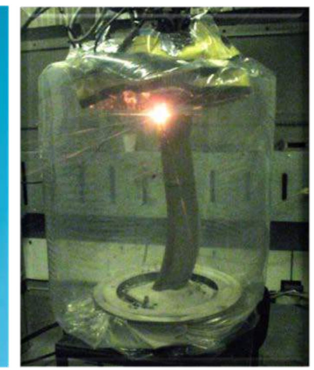
Additive Manufacturing at TWI

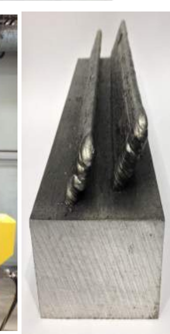
Fully integrated approach

- Design
- Stress Modelling
- Arc based processing
- Eb based processing
- Thermal spray
- Laser based processing
- Metallurgical Analysis
- Heat treatment
- Power quality/recycling
- NDT in and post process
- Mechanical testing
- Standards





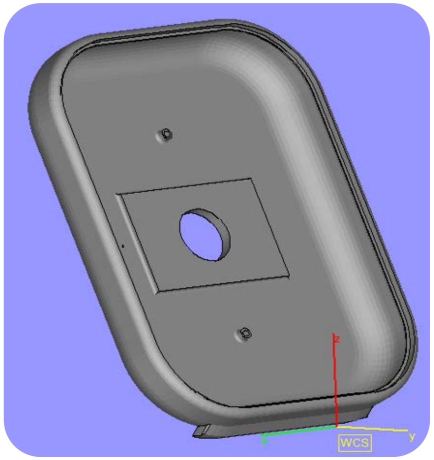


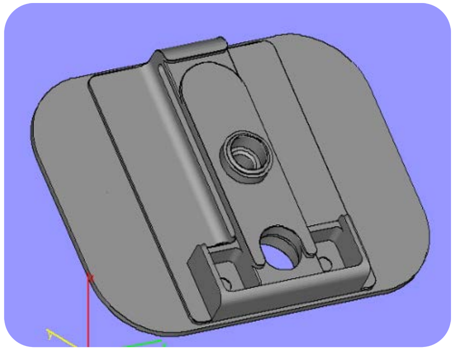


Where TWI can assist?

- Design for Additive Manufacturing
- Topology Optimisation , Light weight Structures (LWS)
- Current Materials – Titanium , Nickel, Aluminium, Steel & Cobalt Chrome Alloys
- Process & Procedure development for new materials
- Complex geometries – for e.g. Internal cooling channels,
- Large parts built by segmented approach – Joined by welding methods
- Mechanical & Metallurgical Analysis / Assessment of AM Builds
- Post Processing of SLM components
    - Advise on appropriate methods
    - Arrangement of sub-contracting
    - NDT inspections of AM Parts
- QA procedure development(compliant applicable AM standards)
- Pre-production Trials

Selective Laser Melting (SLM)

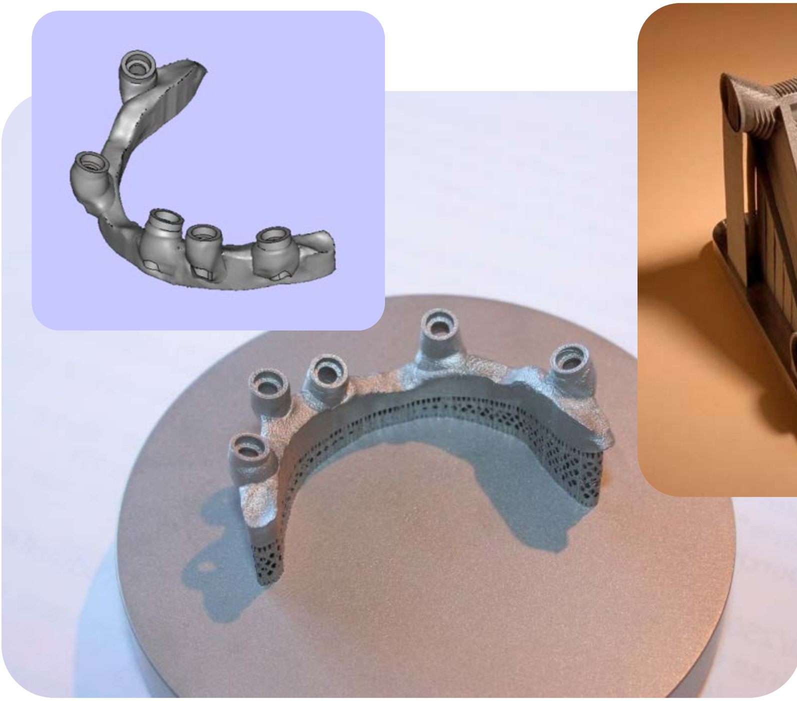


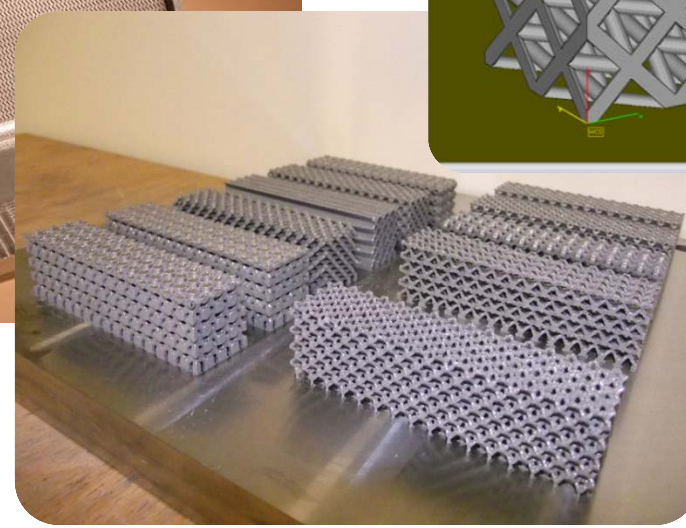
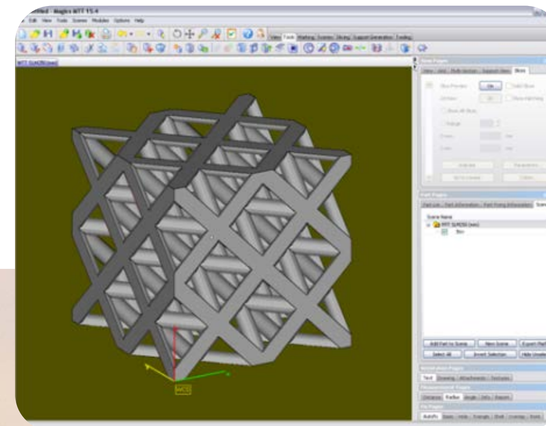


Images Courtesy of TWI

SLM Drivers for Uptake

- Customisation
- Multiple assemblies manufactured as one
- Design complexity/optimisation



Images Courtesy of TWI

SLM vs LMD

Characteristics	LMD	SLM
Materials (procedures development)	Large Materials Diversity (Ni, Ti, Al, CoCr alloys….)	Large Materials Diversity
Multi-Material Capability	Yes (metal matrix, FGM)	No
Part Dimensions	Limited by manipulation system (e.g. 1000x500x2000mm)	Limited by the process chamber (e.g. 600x400x400mm).
Part Complexity	Self supporting (Limited)	Nearly Unlimited
Dimensional Accuracy	>200 µm	>100µm
Roughness (Ra)	40 -100µm	>5µm
Substrates	OEM part (conformal) surfaces	Flat build plate
Layer Thickness	200µm – 3mm	>20µm – 200µm
Powder Particle size	45 - 100µm	15-45µm
Applications	3D parts, surface cladding, OEM repair	Complex 3D parts

SLM Capability at TWI

Realizer SLM100

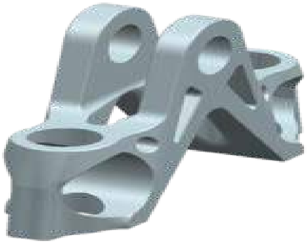
Renishaw AM250

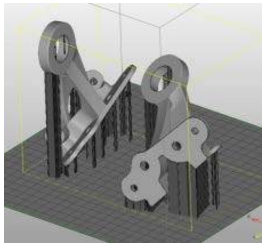
Realizer SLM 50

RapidPart System 1kW

Images Courtesy of TWI

SLM Development Workflow





Topology Optimisation

- Light-weighting
- Lattice sub-structures
- ATOM and TOSCA software

Design for AM

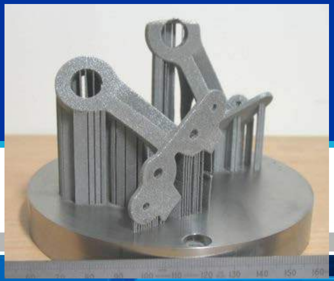
- Dimensional accuracy
- STL Re-design
- Materialise 3-Matic STL Software

Part orientation

- Critical surfaces
- Post-processing
- Materialise Magics

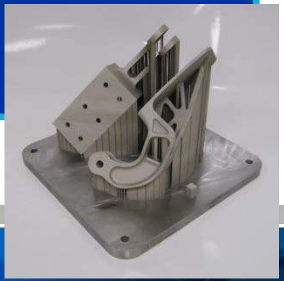
Support generation

- Solid supports & tree-like structures



Prototype generation

- Process parameter developments

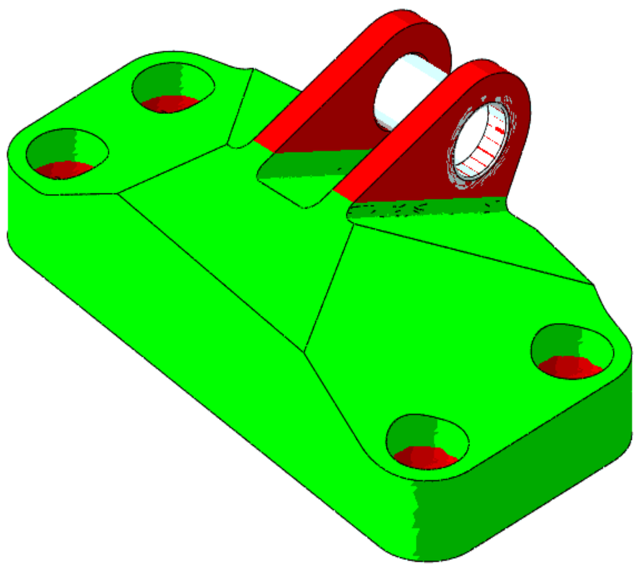


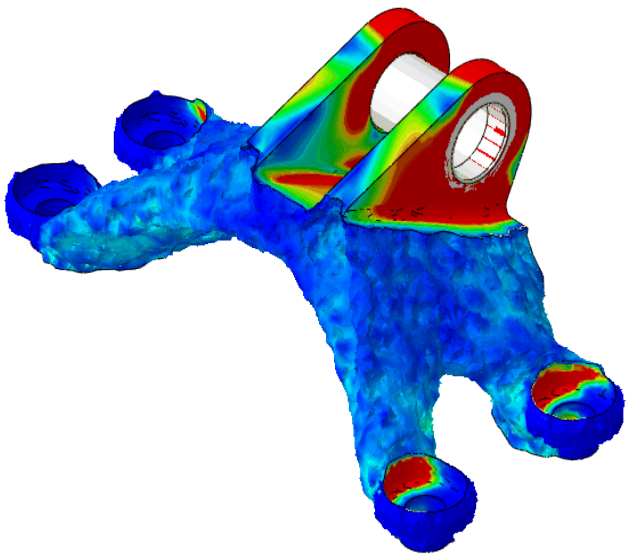
Production trials

- Process parameter development

TWI

Topology Optimisation

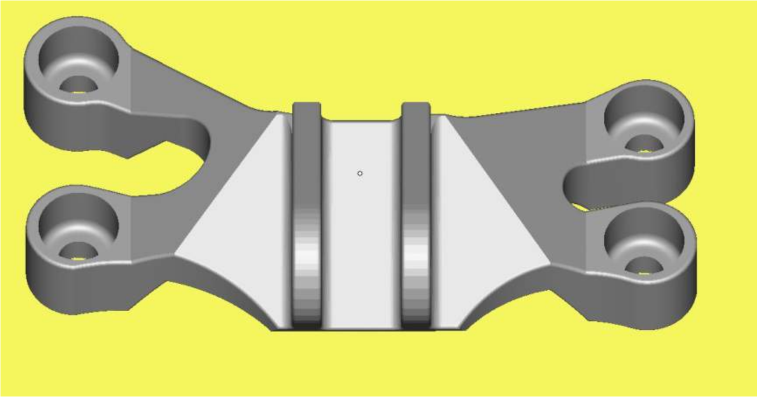


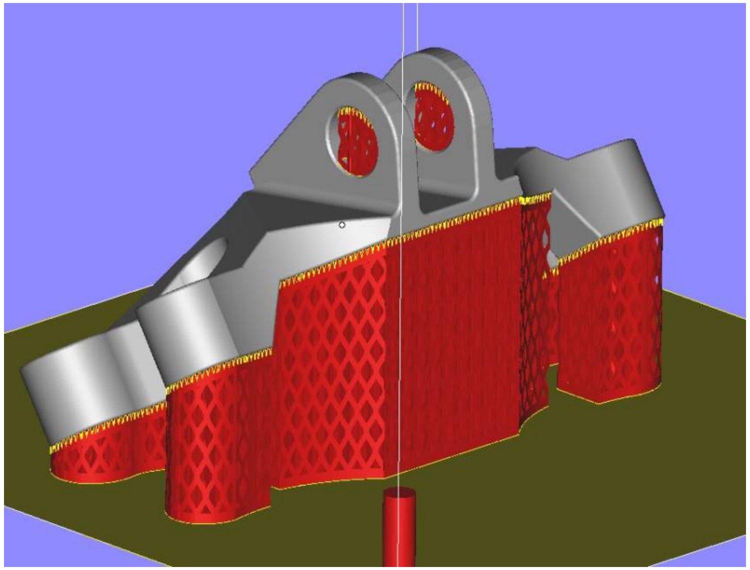


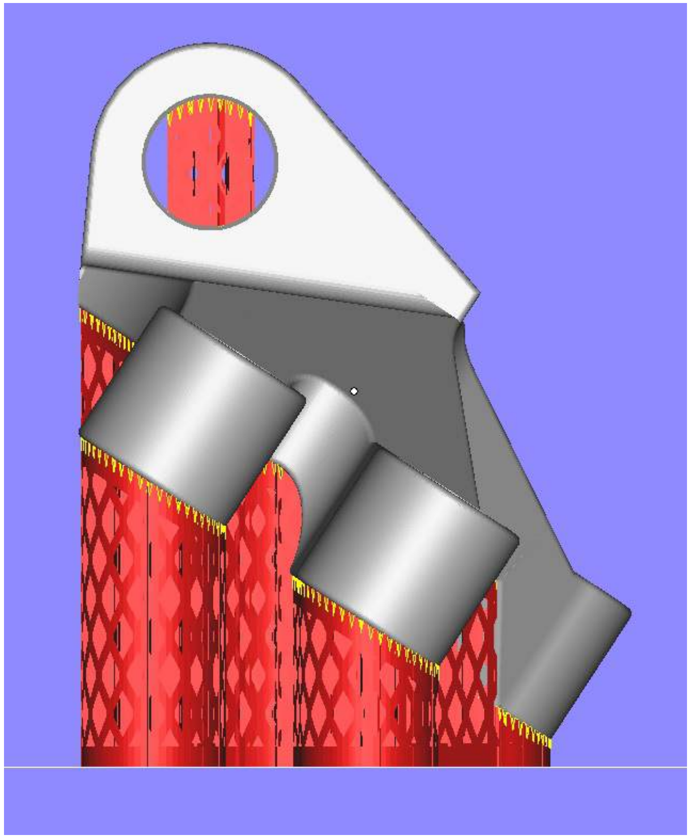
ManSYS
3Dprintingplatform.com

Orientation and Support Generation

- Residual Stresses
- Ease of Removal
- Better Surface Finish
- More parts on platform

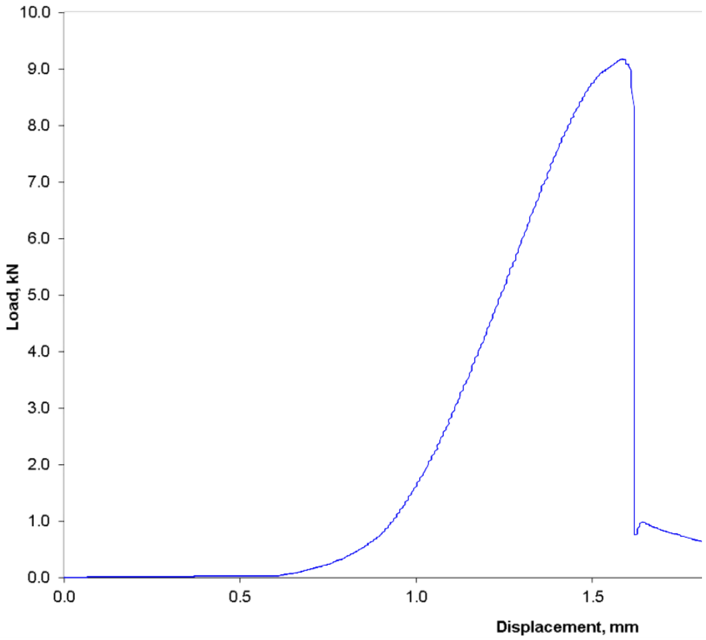






Verification of Materials Performance

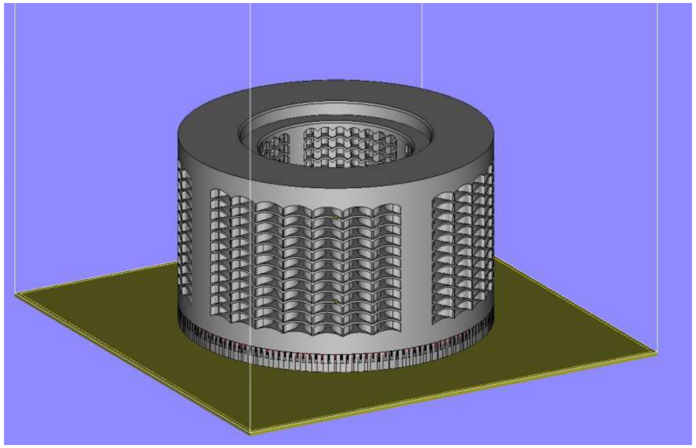
- SLM tensile specimens and fatigue samples
- Enables verification of post-processed material performance and input for FEA
- Metallographic examination of composition & defects

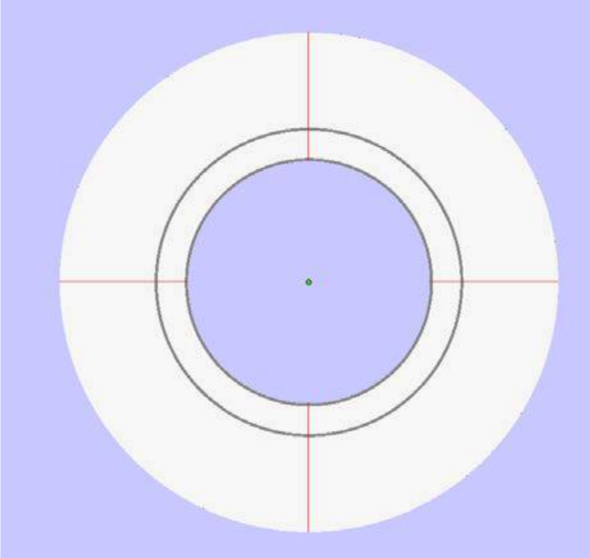


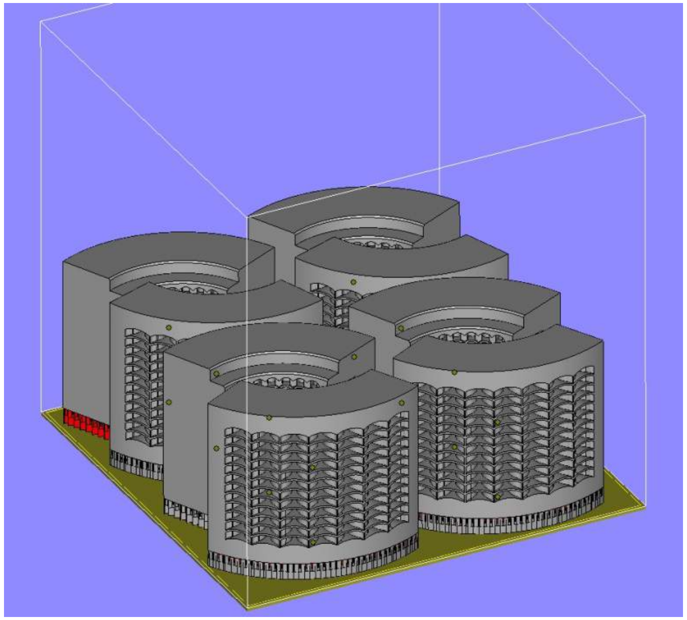
Approach for Large Structures

Segmented Approach for large parts

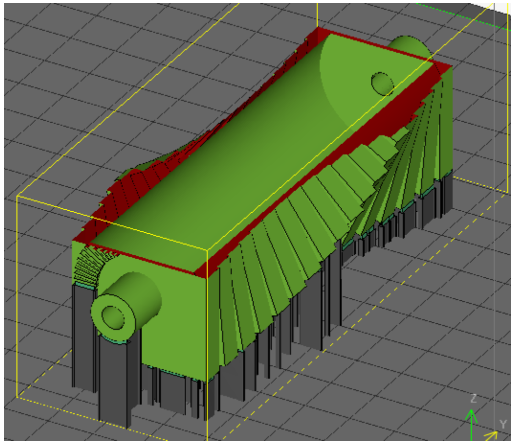
- Cost effective
- Reduced Lead Time
- Joining using latest welding methods







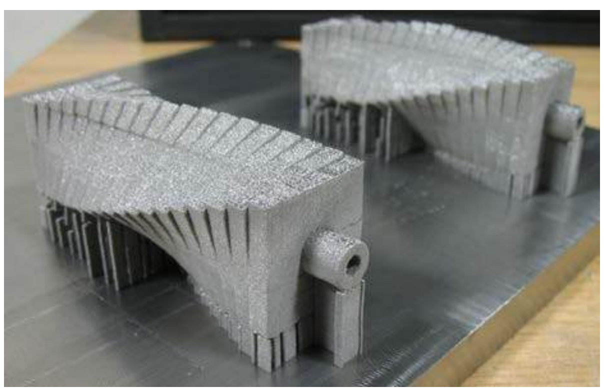
Post-Processing Requirements



AM Post-processing

- **Remove part from substrate**
  - Manually
  - Sawing
  - Water jet cutting
  - EDM wire cutting

- **Remove substructures**
  - Milling
  - Drilling / Turning
  - Grinding
  - Polishing



NDT techniques

- Five main techniques available:
  - Photography/Thermography
  - Laser Ultrasonics
  - Laser Thermography
  - Eddy Current
  - X-Ray
- Work ongoing to provide data to make the techniques more applicable
- Some success in detecting relevant flaws at representative depths within the material

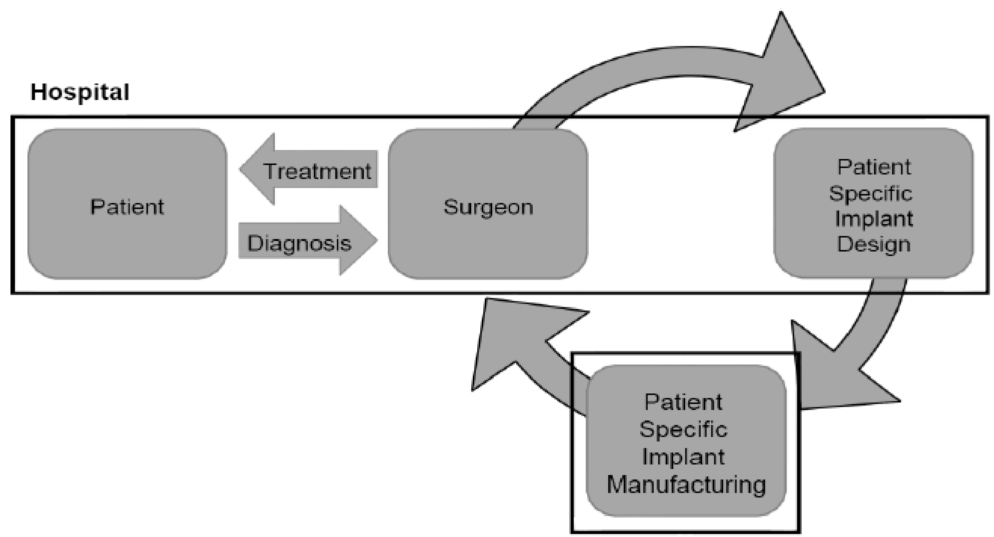
Current TWI Project - ImplantDirect

www.implantdirect-project.eu

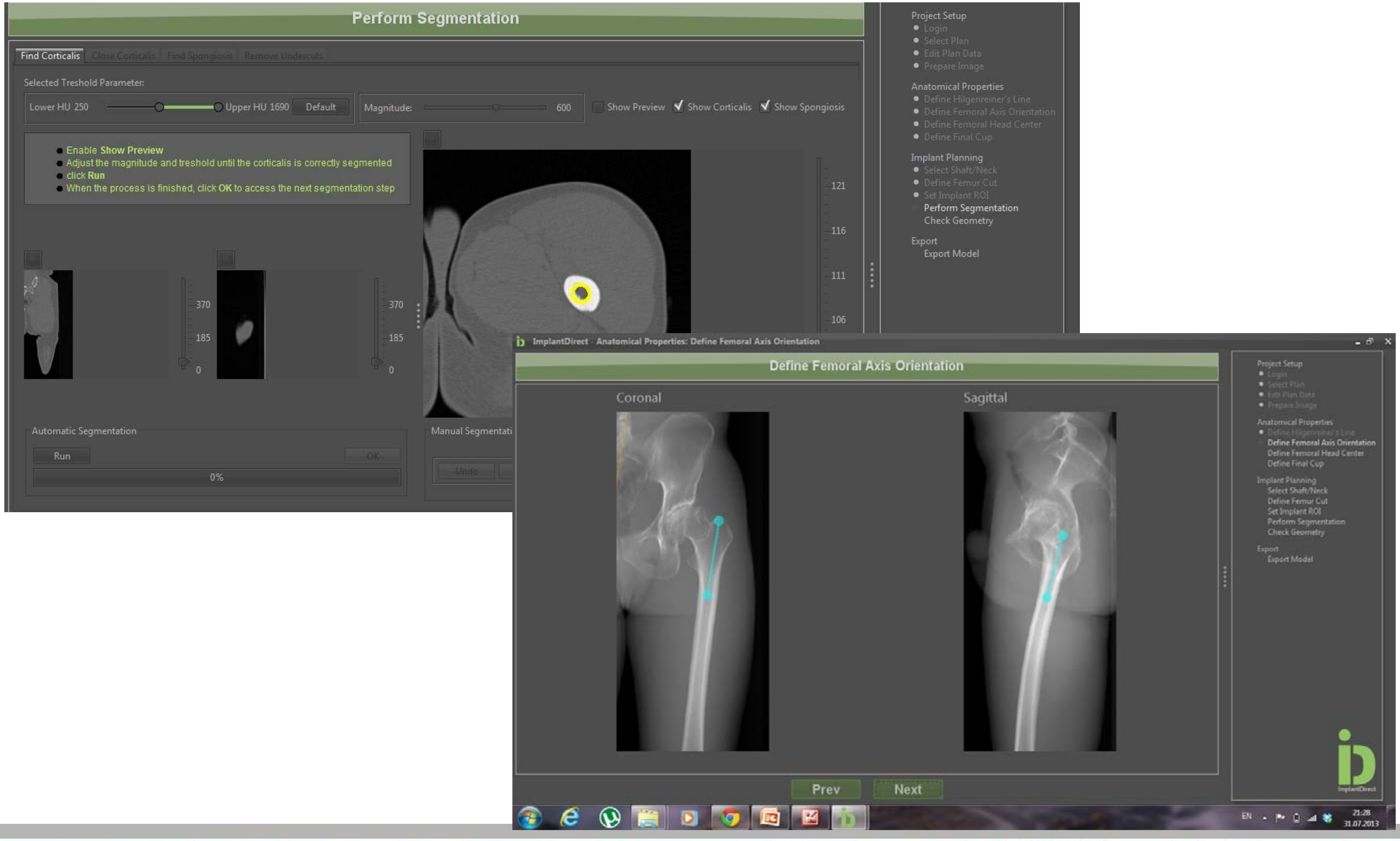
The research leading to these results has received funding from the European Union's Seventh Framework Programme managed by REA Research Executive Agency [FP7/2007-2013] under grant agreement no 2623859

Images Courtesy of ImplantDirect

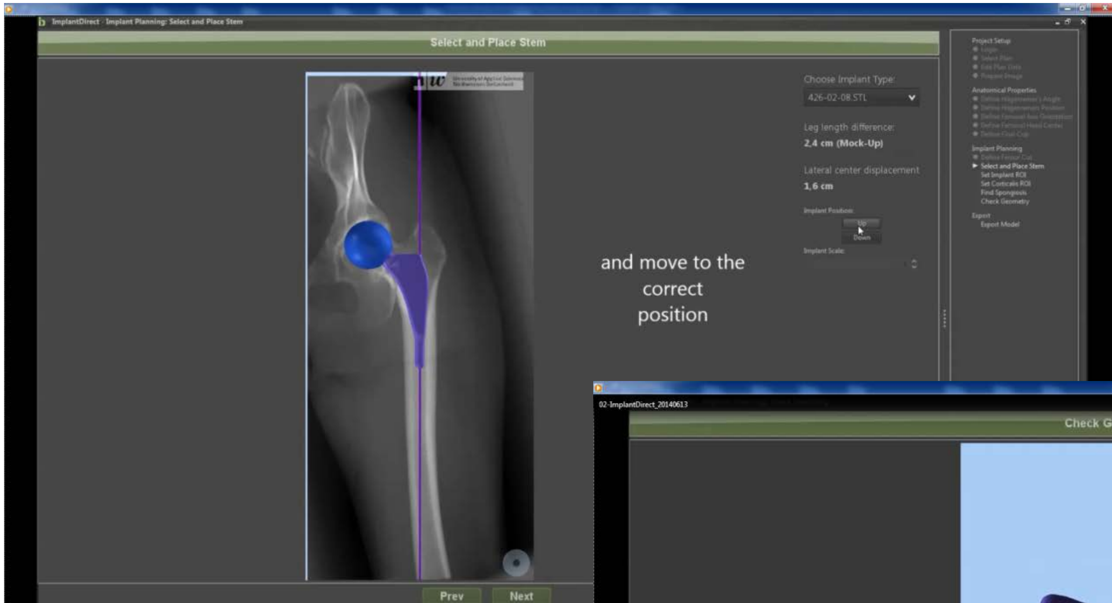
- Demonstration of ability to manufacture a patient-specific medical implant with a turnaround of 7 days
- Development and testing of an integrated software solution for designing and manufacturing
- Development of the SLM process and post-processing for the manufacturing of personalised medical implants according to EC Directives.

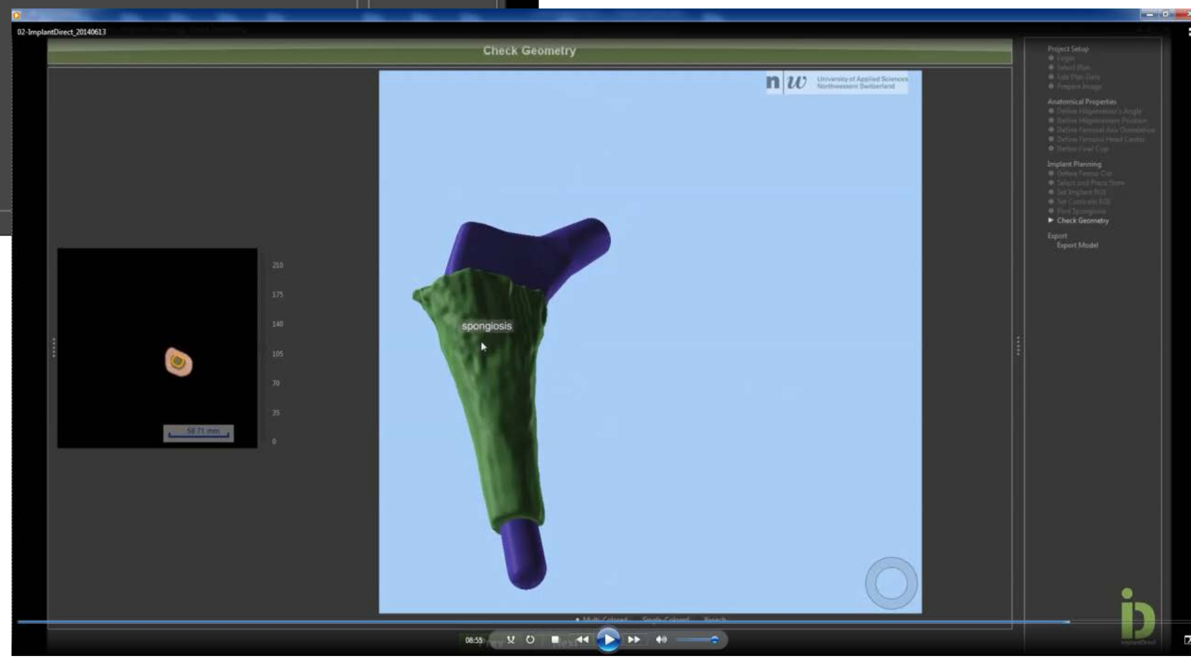


Patient specific implant design

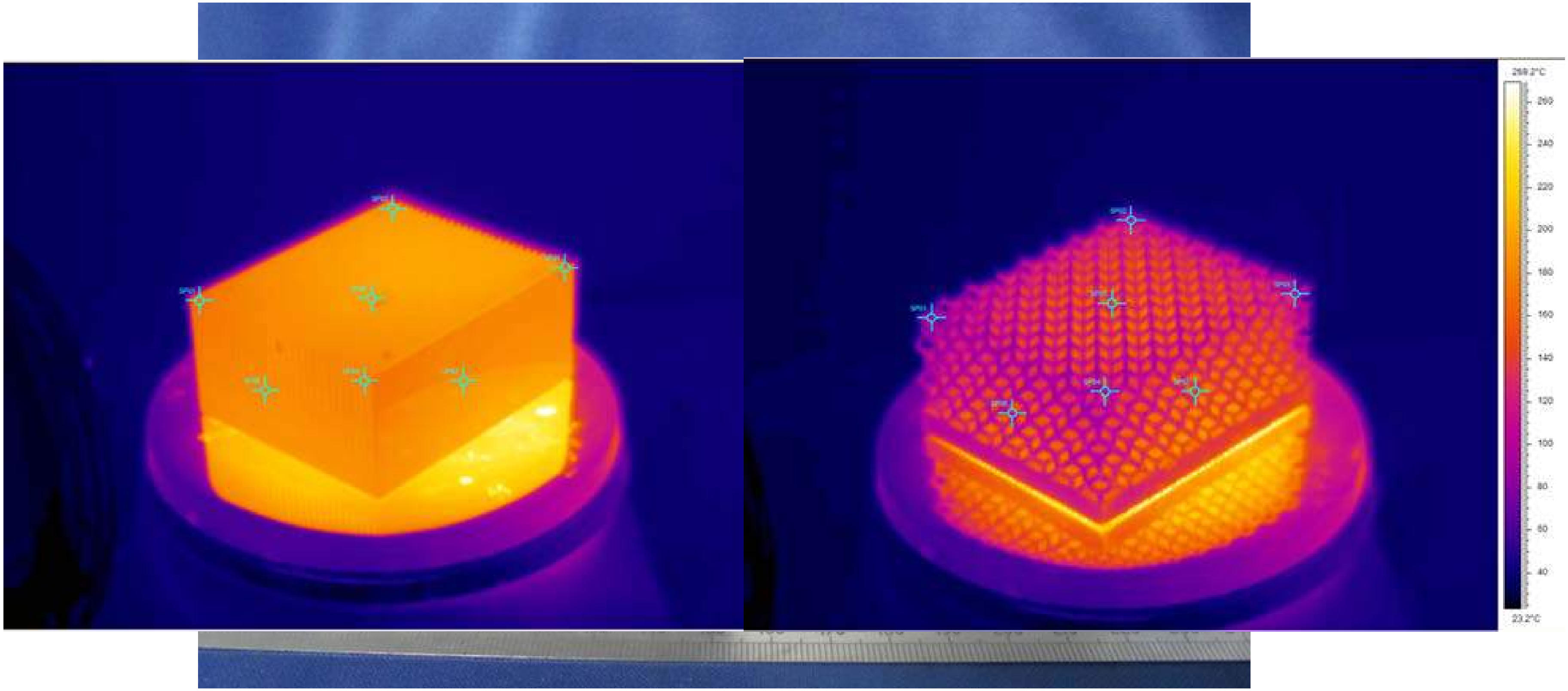


Surgeon is the designer



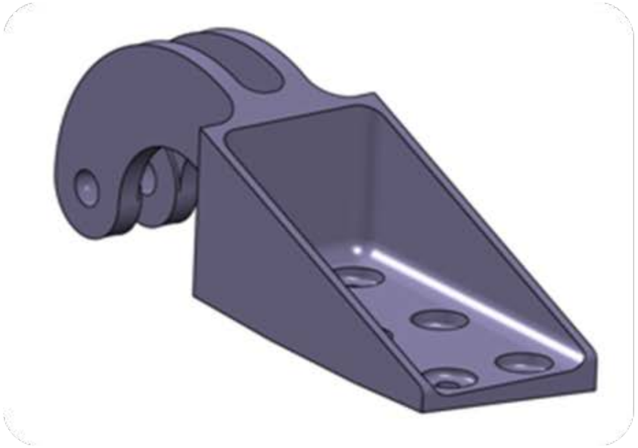


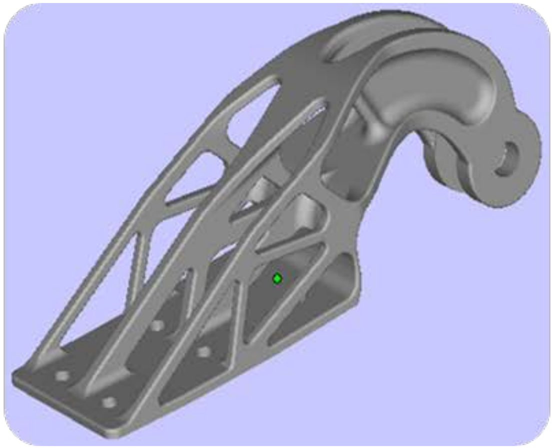
Case Study – Heat Exchanger



Case Study - Aerostructure

Structural efficiency can be improved by enabling optimised topology that could not normally be achieved by machining or casting.





A collaboration between the following organisations: TWI Ltd, University of Exeter, EADS UK, Bombardier Aerospace plc, TISICS Ltd and Materialise UK. The Project was managed by TWI Ltd and partly funded by the TSB under the Technology Programme ref: “AB183A”. TP No: TP11/HVM/6/I/AB183A

Case Study - Custom Hip Implants

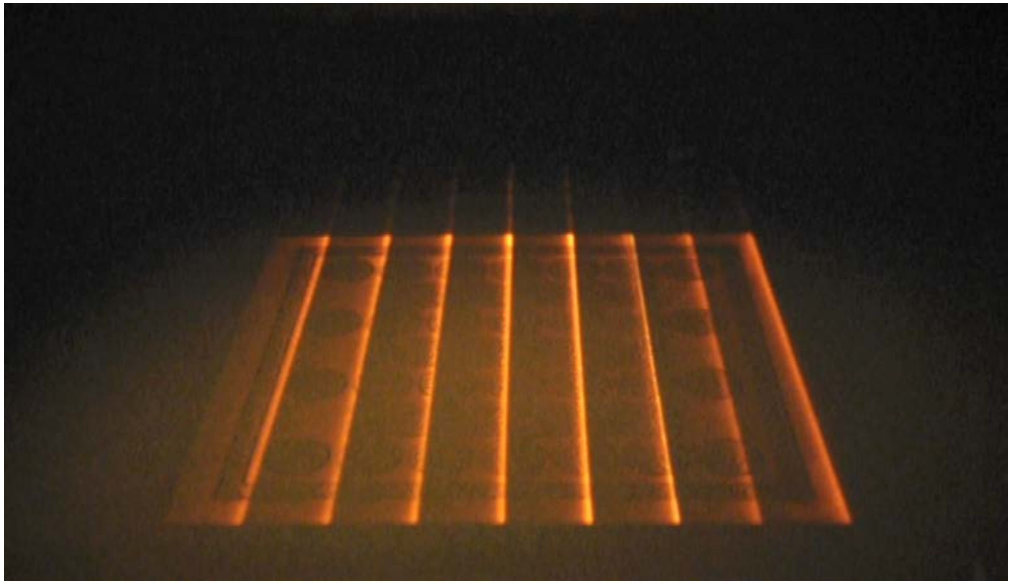
- InnovateUK project
- Idealised mesh design for bone in-growth created
- Suitable material properties developed for SLM process
  - Static tests - 0.2% PS 915 MPa vs 860 MPa spec

UTS	1015 MPa	vs 930 MPa	spec
El%	15%	vs >10%	spec
RA%	45%	vs >25%	spec

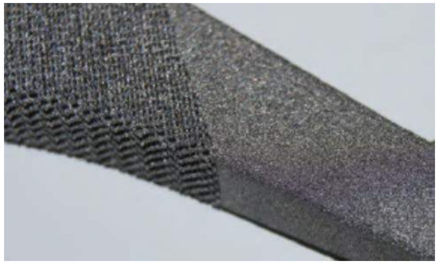
  - Fatigue – HIPped test specimens exceeded industry standard for Ti medical implants, 600MPa >10million cycles
- Customised hip/pelvic implant produced in one build with complex mesh design on SLM equipment. Polished and cleaned to medical standards suitable for implanting.

Partners: Bodycote HIP, Stanmore Implants, Materialise, and LPW Technology

Electron Beam Melting (EBM)



Courtesy of Arcam and Avio SpA



EBM vs SLM

Characteristics	EBM	SLM
Materials (procedures development)	Large Materials Diversity (Ti, TiAl, CoCr alloys....)	Large Materials Diversity
Multi-Material Capability	No	No
Part Dimensions	Limited by the process chamber (e.g. 350mm diax380mm)	Limited by the process chamber (e.g. 600x400x400mm)
Part Complexity	Nearly Unlimited	Nearly Unlimited
Dimensional Accuracy	+/-100µm typical	>100µm
Roughness (Ra)	25µm typically	>5µm
Substrates	Flat build plate	Flat build plate
Layer Thickness	50-70µm	>20µm – 200µm
Applications	Complex 3D parts	Complex 3D parts

EBM Machine Sales

- ~120 EB welding machines sold globally each year
- ~30 Powder bed EB additive m/c sales in 2014 and >40 forecast in 2015 by Arcam AB (EBM process)
- Secondary capabilities of welding machines are vast…

Sustaining

- Heat treat
- Cosmetic treat
- Surface nitride
- Surface mark
- Surface texture
- Surface sculpt
- Vacuum remelt

Subtractive

- Drilling
- Cutting
- Micro-machine

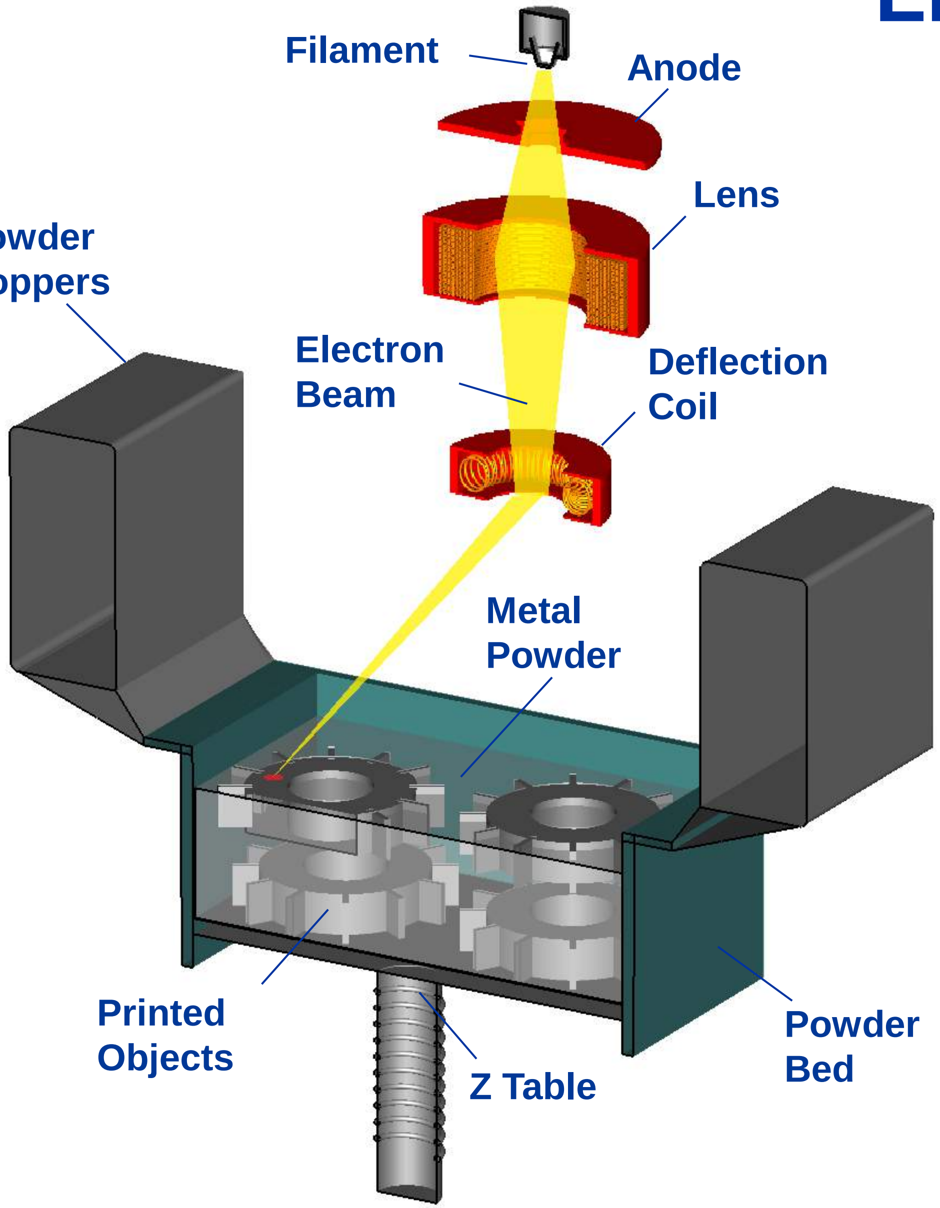
Additive

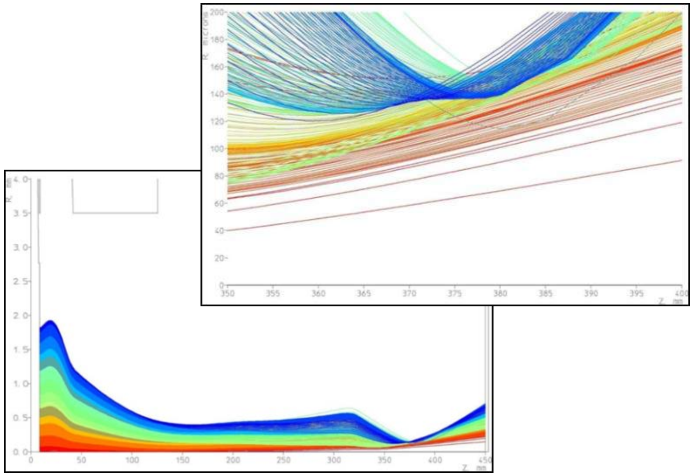
- Wire additive
- Powder additive

EC Funded EBM Projects at TWI

- HiResEBM Project: www.hiresebm.eu
  - Optimisation of EB powder bed additive manufacturing equipment for high resolution medical components
- FastEBM Project: www.fastebm.eu
  - Optimisation of EB powder bed additive manufacturing equipment for rapid, 10kW, production of larger components
- TiAlCharger Project: www.tialcharger.eu
  - EB powder bed additive manufacturing and welding for TiAl turbocharger assemblies

EBM Technology & TWI Activities





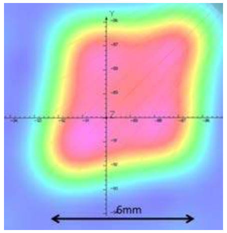
EBM Additive Repeatability… Addressing the Challenge

- Address manual setup & calibration variability
  - Current practice is time consuming
  - Operator dependant
  - Must be completed frequently

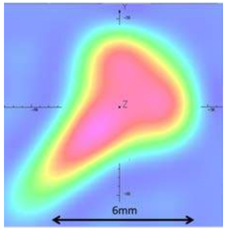
- Beam thrown off-axis (≤175mm from free-fall) distorts & compensation must be made

- Lessen need for batch test pieces

- <u>Transferability between machines?</u>
- <u>Repeatability on same machine?</u>



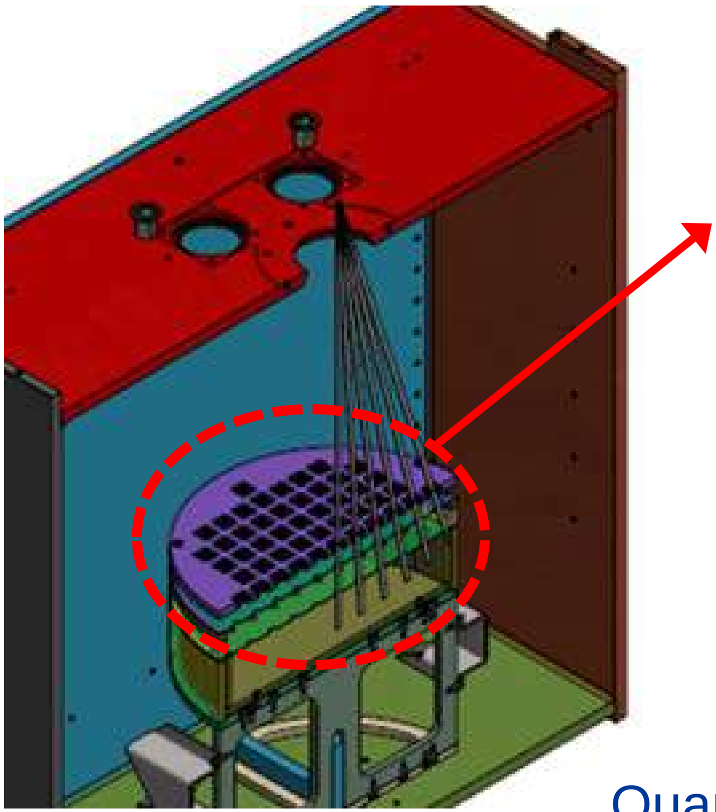
Example of spot distortion as deflection is applied

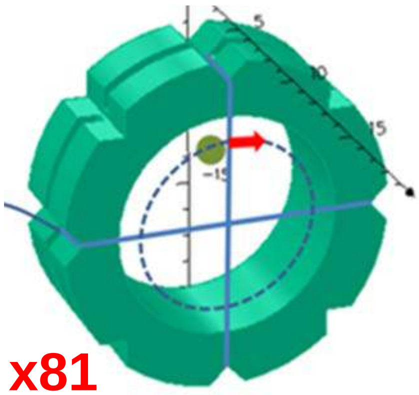


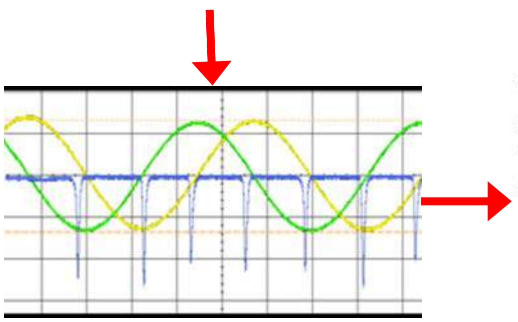
The research leading to these results has received funding from the European Union's Seventh Framework Programme managed by REA – Research Executive Agency http://ec.europa.eu/rea (FP7/2007-2013) under grant agreement no FP7-SME-2012-315226

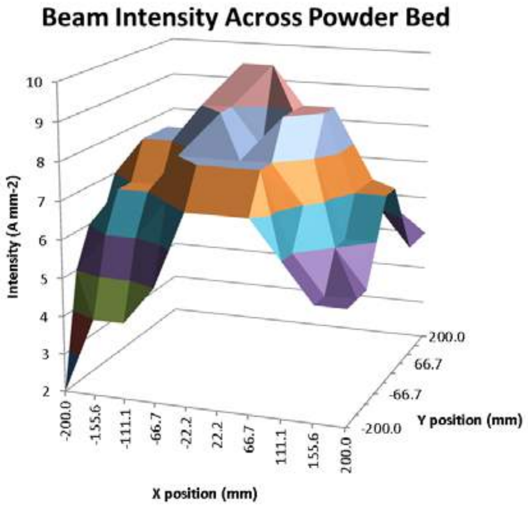
TWI Developmental EBM QA Probe

Patent app filed Feb 2014 – Ongoing development





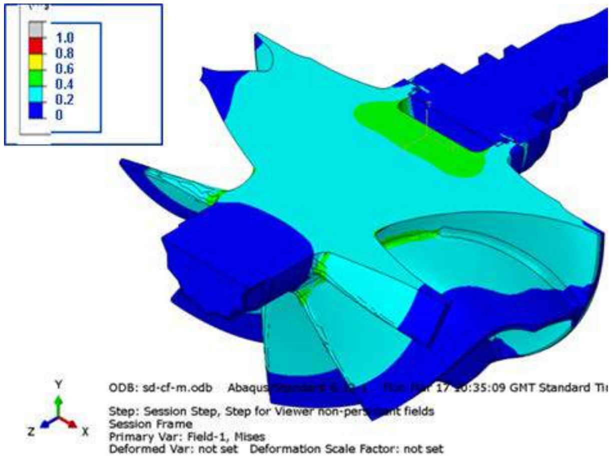




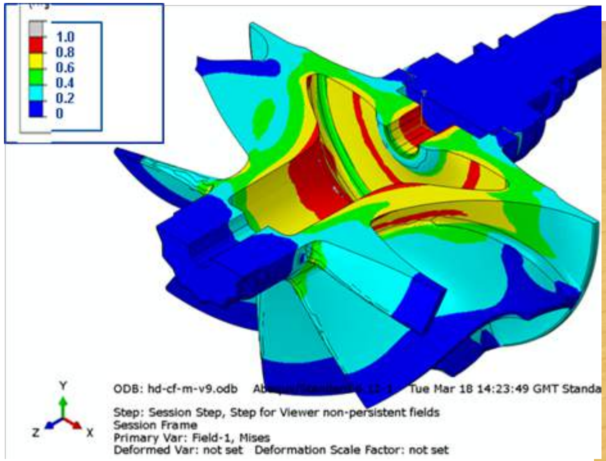
Quantified measurements
across the whole powder bed

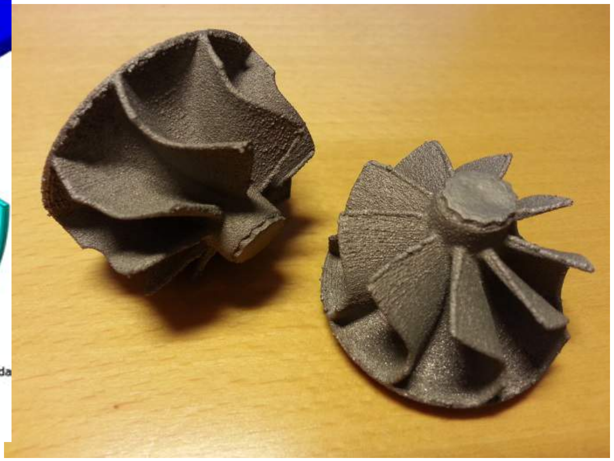
TiAl EBM Rotor EB Brazed to Steel Shaft

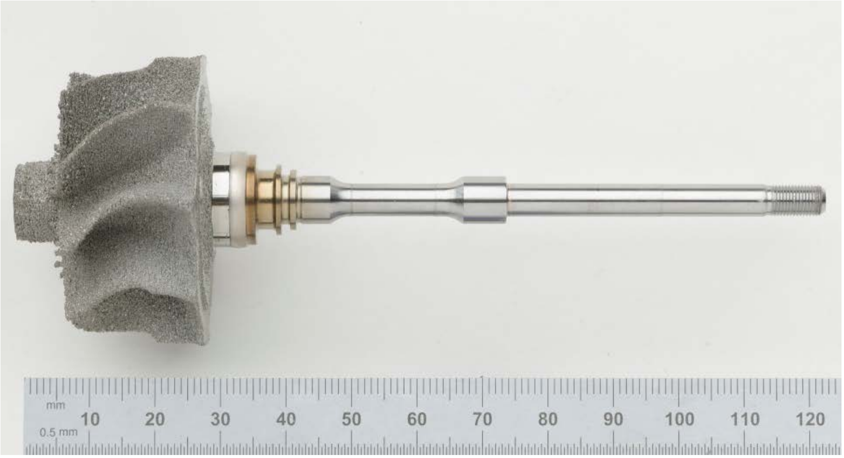
Normalised Von Mises Stress (MPa)

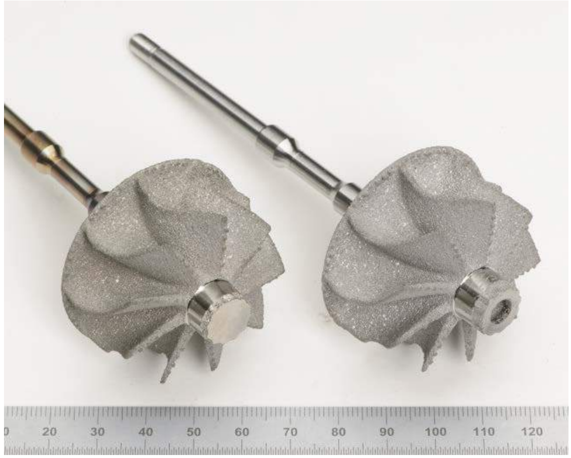


Normalised Von Mises Stress (MPa)









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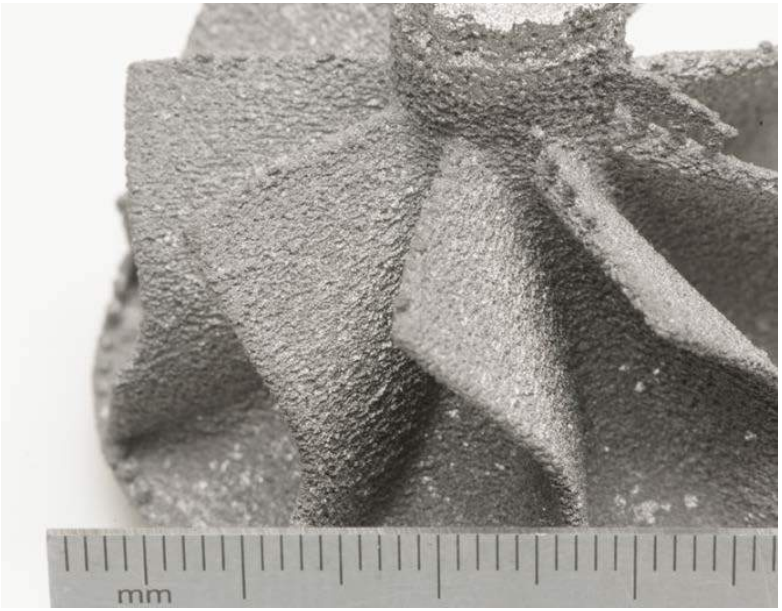
Surface Finishing Trials



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TWI

TWI and Lloyds Register Energy Joint Industry Project (JIP)

Certification of Laser Powder Additive Manufactured Components for Industrial Adoption in the Energy and Offshore Sectors

Materials Joining and Engineering Technologies

Background

- Revolutionary technology does not automatically result in saleable products overnight.
- Barriers - Legal, safety, reliability & repeatability.
- International standards and regulations are there to overcome these.
- ISO and ASTM standards are in development now and will tackle a number of the challenges facing the AM community:
  - CAD model translation
  - Powder size and quality
  - Recyclability of powder
  - Variability between AM machine models
  - Support structures
  - Build parameters
- However, these are the challenges that designers and manufacturers face now.

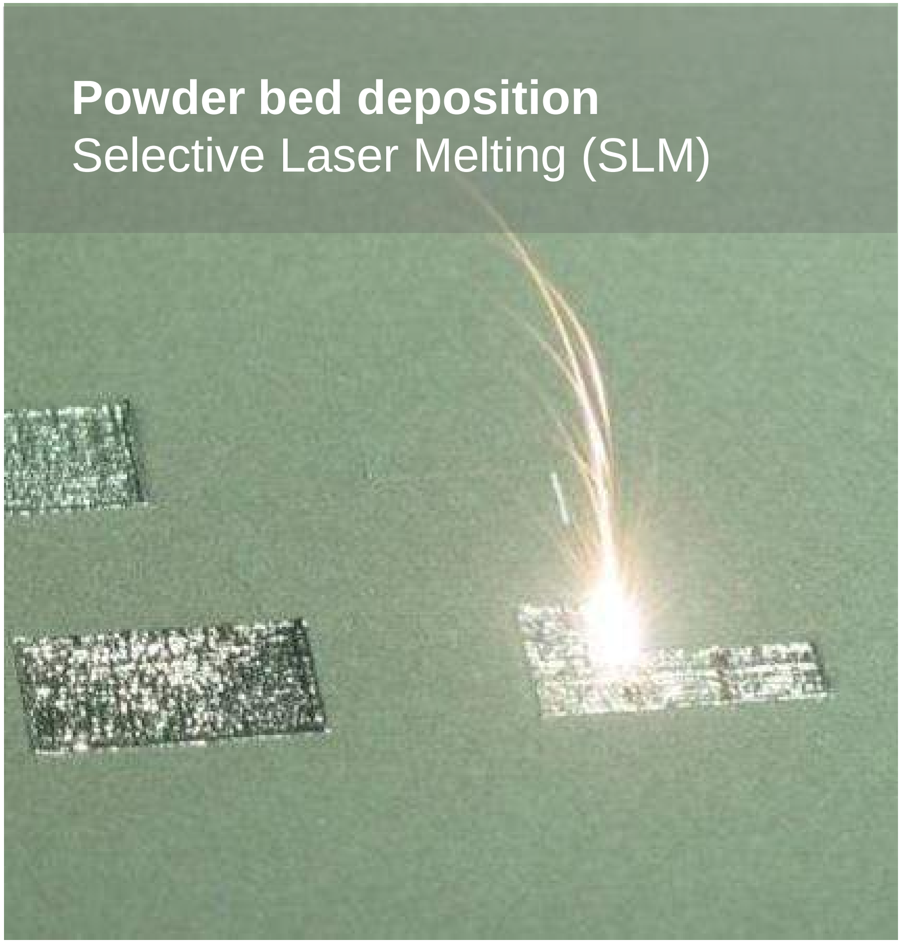
TWI and Lloyds Register created JIP to:

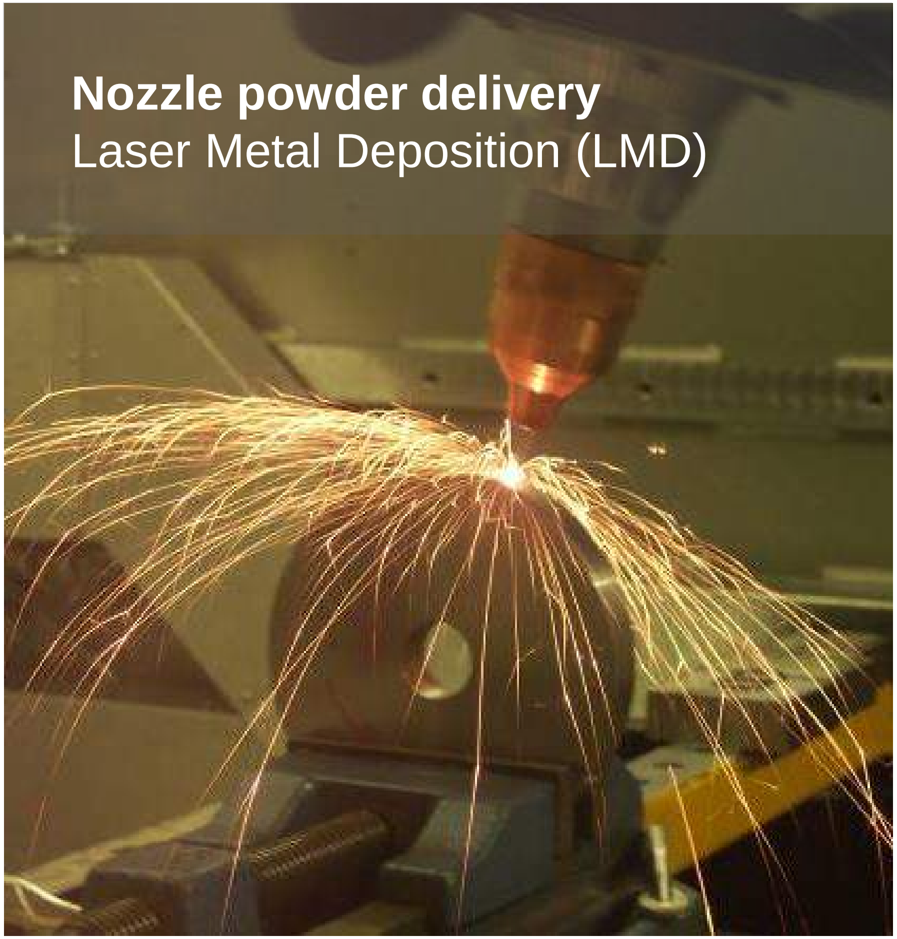
forge a path to market
remove barriers
provide expert advice

JIP Outline

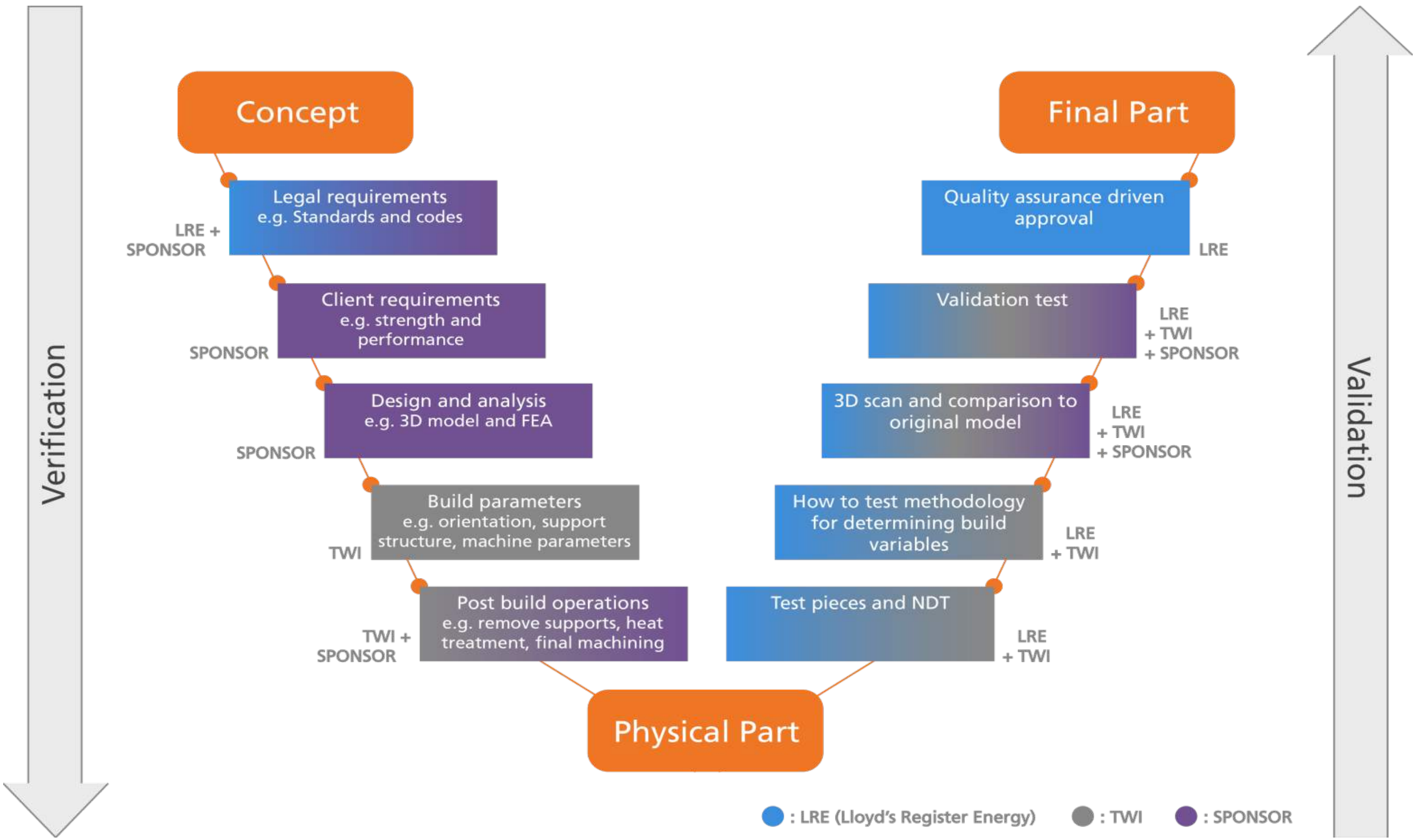
- Focus on case studies in the Energy, Oil & Gas and Marine sectors.
- Looking for manufacturers with AM parts to join this 12 to 18 month project.
- Undertake practical work to determine optimum build parameters for the components.
- Determine required inspection activities to certify components.
- Generate AM Certification Guidelines, based on certification of the selected components.
- These AM Certification Guidelines will provide the roadmap to certifying future AM parts.

Additive Manufacturing Technology





Approach



Verification
Concept
Legal requirements
e.g. Standards and codes
LRE + SPONSOR
Client requirements
e.g. strength and performance
SPONSOR
Design and analysis
e.g. 3D model and FEA
SPONSOR
Build parameters
e.g. orientation, support structure, machine parameters
TWI
Post build operations
e.g. remove supports, heat treatment, final machining
TWI + SPONSOR
Physical Part
Test pieces and NDT
LRE + TWI
How to test methodology for determining build variables
LRE + TWI
3D scan and comparison to original model
LRE + TWI + SPONSOR
Validation test
LRE + TWI + SPONSOR
Quality assurance driven approval
LRE
Final Part
Validation
: LRE (Lloyd's Register Energy)
: TWI
: SPONSOR

Benefits

- **Certified parts that meet industrial requirements** for quality, safety, and consistency, and which are qualified ready for market introduction.
- **Improved knowledge of AM processes and practises** to ensure repeatability and reproducibility and facilitate the certification of future parts.
- **Decreased cost of certification** by leveraging expert processing and certification knowledge and experience from both TWI and LR Energy.

Summary

- TWI activities in Additive Manufacturing
  - From ‘design’...to...’process’... to....’validation’....
- AM Processes supported include:
  - Laser – SLM and LMD
  - Electron beam – EBM and Wire-fed
  - Arc and thermal spray
- Large number of current initiatives on
  - Equipment development
  - Process development
  - Supply chain development
- Opportunities to interact with TWI on AM
  - SCP
  - JIP

Further Information

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E-mail: jon.blackburn@twi.co.uk

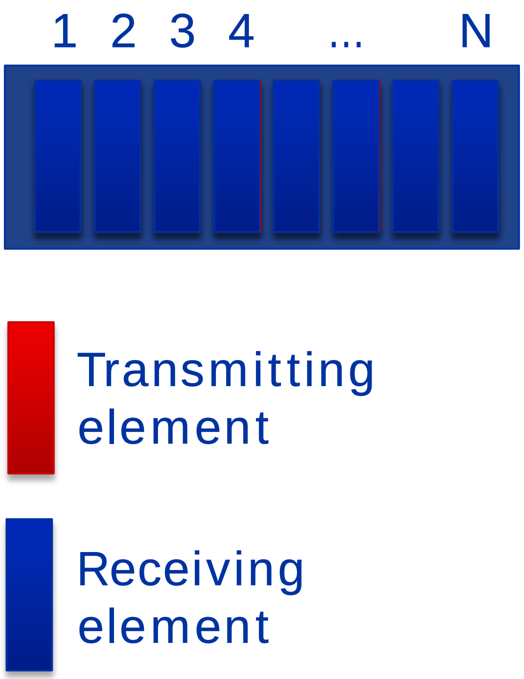
Next Generation Ultrasonic Inspection

Materials Joining and Engineering Technologies

Full Matrix Capture

- A data acquisition strategy that captures every possible transmit and receive combination for an array transducer
- No focussing during the transmit or receive cycles
- Fully focussed imagery through DSP post-processing
- Made possible now that multi-element (PA) probes are commonly available

FMC Data Acquisition



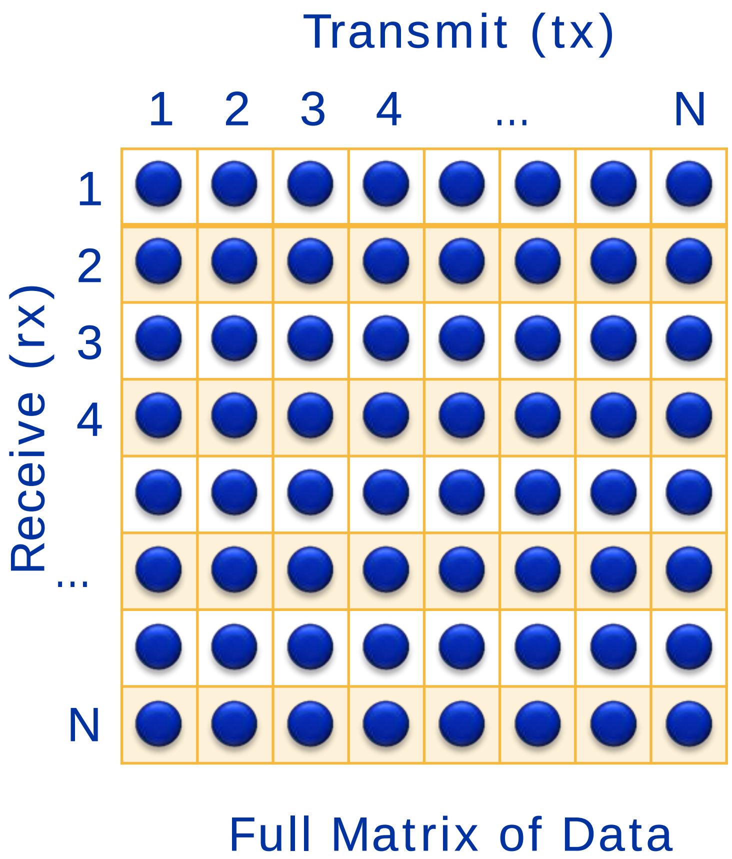
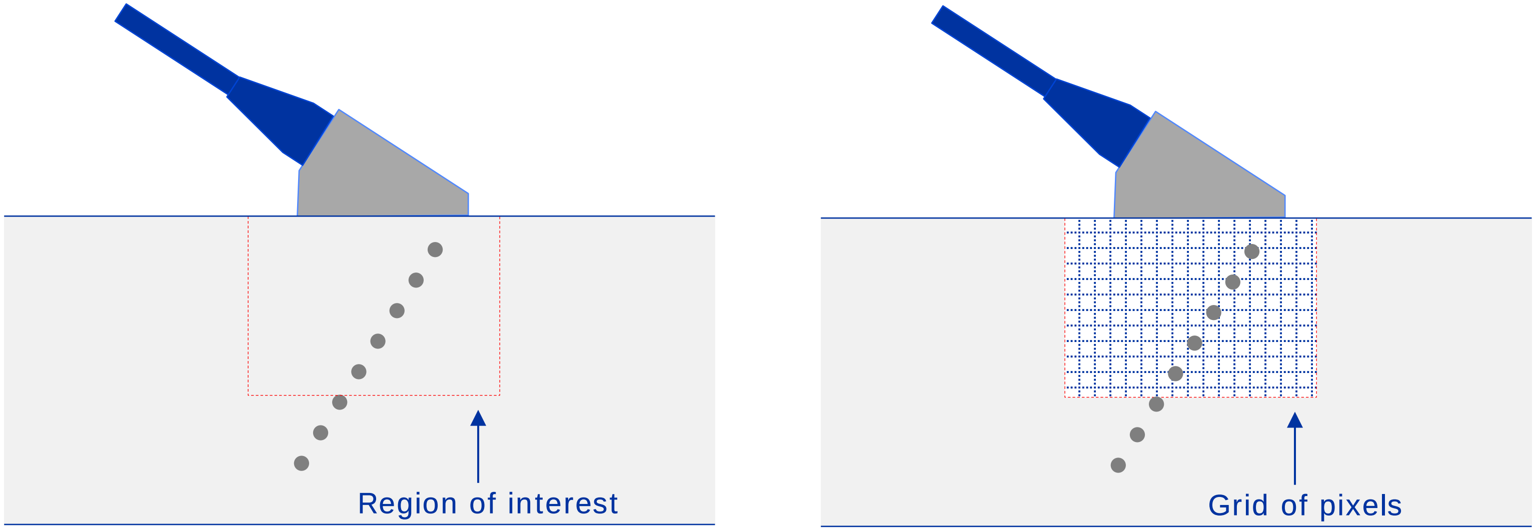
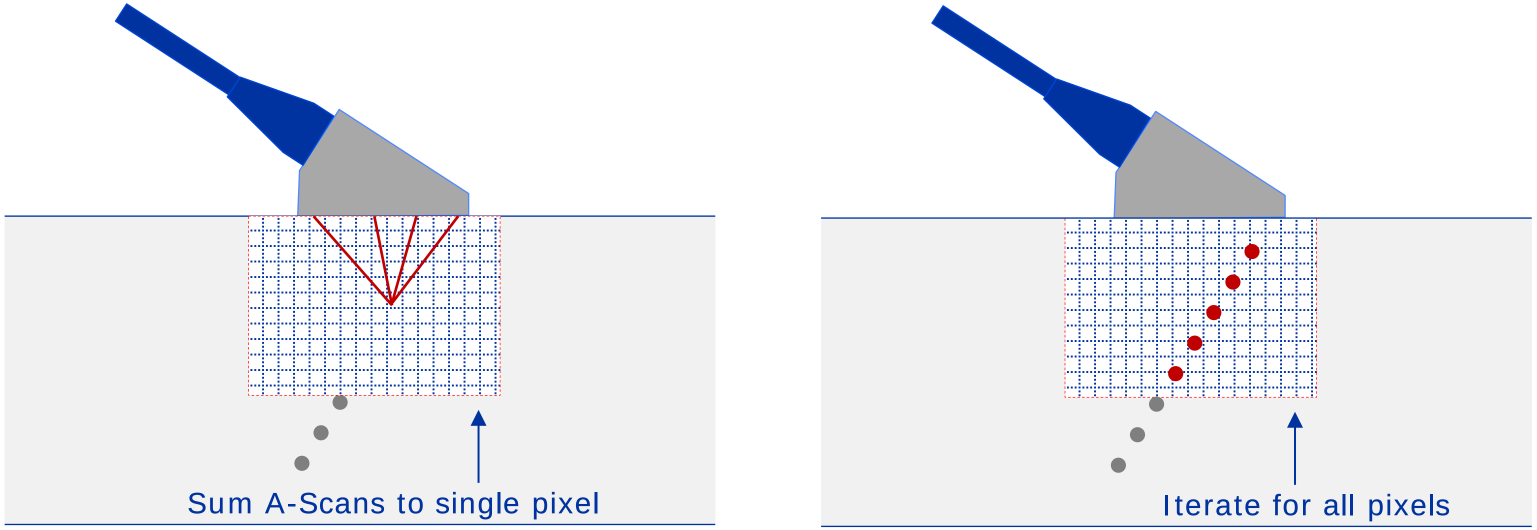


Image Reconstruction



- Region of interest defined as a grid of pixels
- Each pixel has a contribution from every tx/rx combination
- Iterate for all pixels

Image Reconstruction



- Region of interest defined as a grid of pixels
- Each pixel has a contribution from every tx/rx combination
- Iterate for all pixels

FMC Major Challenges

- Data Acquisition
  - 64 elements = 4096 A-scans (64^2)
  - A-scan length of 1,000 sample points
  - Sampled at 16 bit resolution
  - 7.81 MB of data
  - Micropulse = 6 acquisition per second
  - Cicada = 32 acquisitions per second

FMC Major Challenges

- Processing
  - 64 elements = 4096 A-scans (64^2)
  - Region of interest 100 x 100 pixels
  - 41M TOF calculations to generate a single B-Scan

FMC Major Challenges

- TWI Wales have developed a real-time software solution for processing of FMC data

- Communicates with hardware in real-time
- Highly optimised code packaged in lib file
- Compatible with Windows and Linux

- Real time inspection
- Custom processing of FMC data for a variety of scenarios and industry sectors

FMC Capabilities

Research and Development

- FMC Composites
- Complex geometry
- Annular arrays
- Virtual Source
- 2D arrays
- Non-linear FMC
- 3D visualisation
- Robotic integration
- Self-Tandem FMC
- TOFD FMC
- Cross-platform (Linux)

Commercial Software

- FMC 32/64 arrays
- Real-time (GPGPU)
- Sub-aperture FMC
- Calibration for FMC
- Visualisation
- Reporting
- 1D linear arrays

System Integration

- MicroPulse
- Cicada
- Files (in correct format)
- MS Windows
- Linux
- NVIDIA GPU

Full Matrix Capture

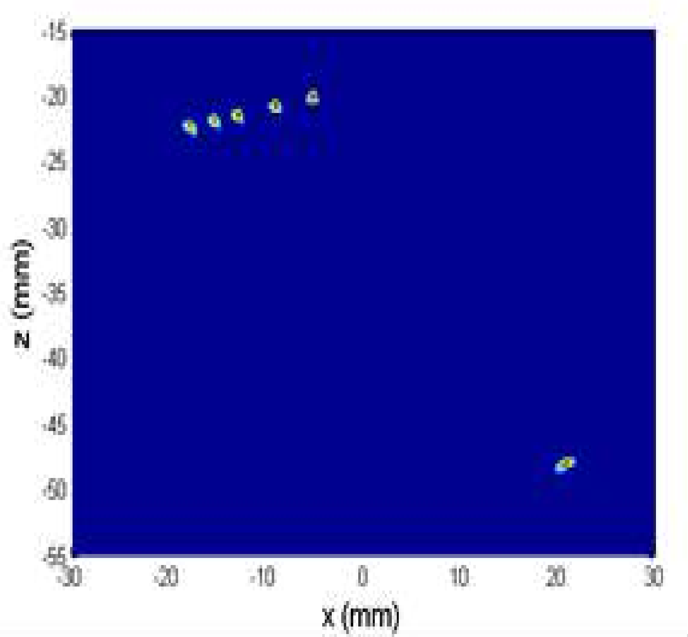
Examples

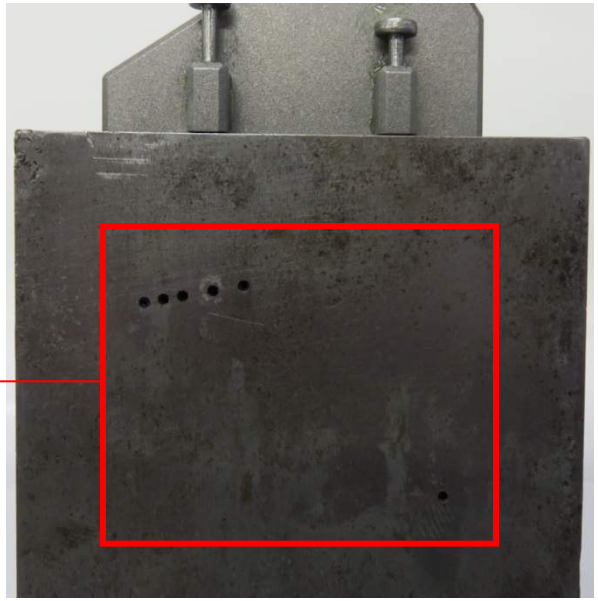
Materials Joining and Engineering Technologies

Inspection of ferritic steel sample

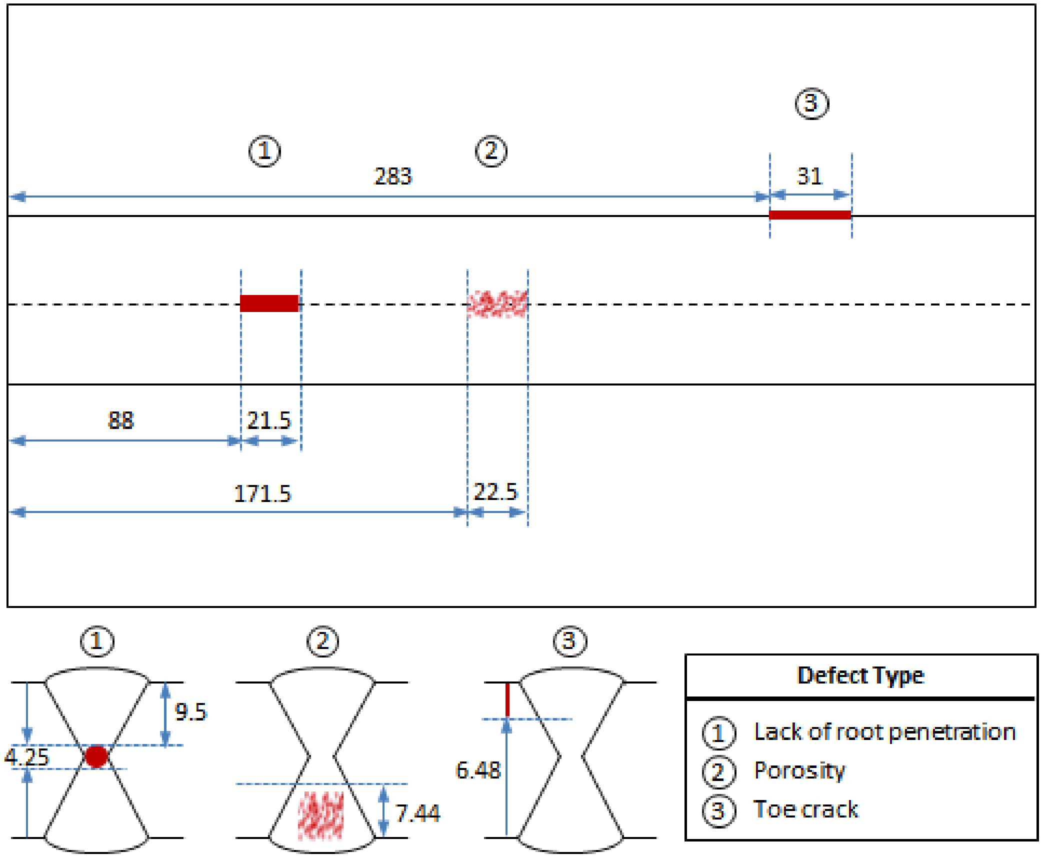
1mm SDHs in mild steel block

- Fully focussed throughout area of interest
- >30 fps real time imaging
- 0.125mm resolution





Weld inspection



Double V-Butt weld

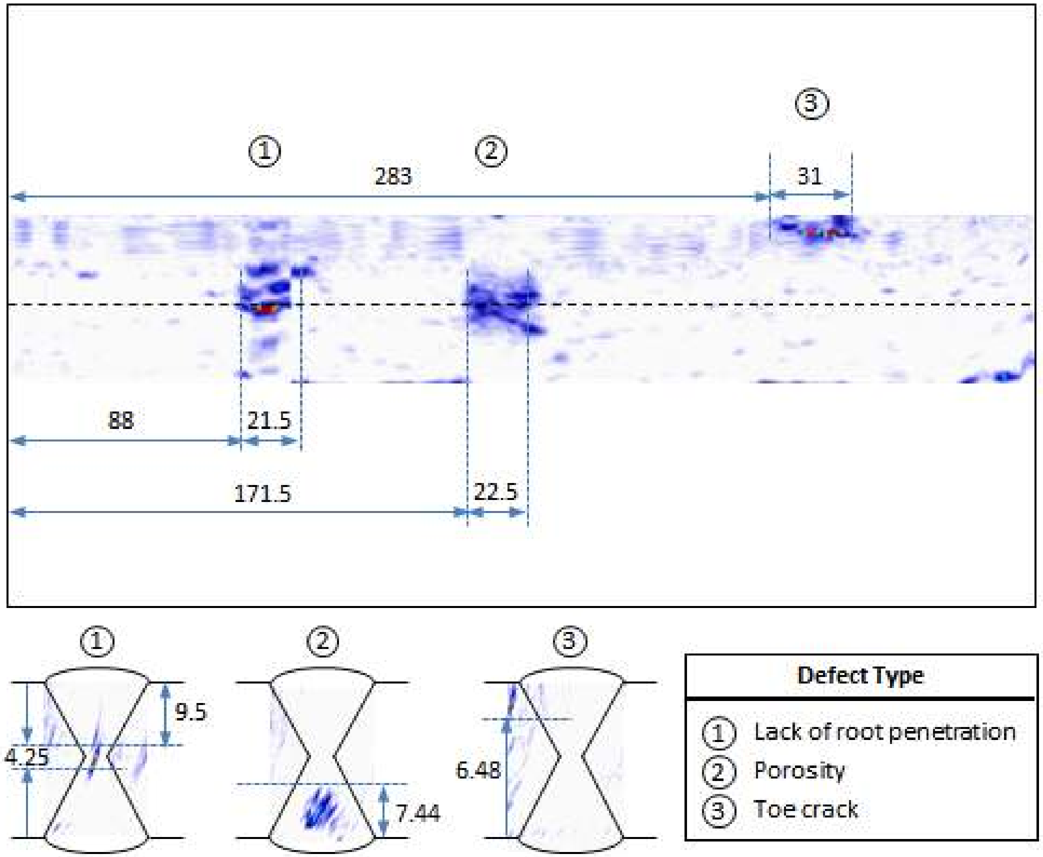
32 element probe + wedge

Weld inspection

Double V-Butt weld

32 element probe + wedge

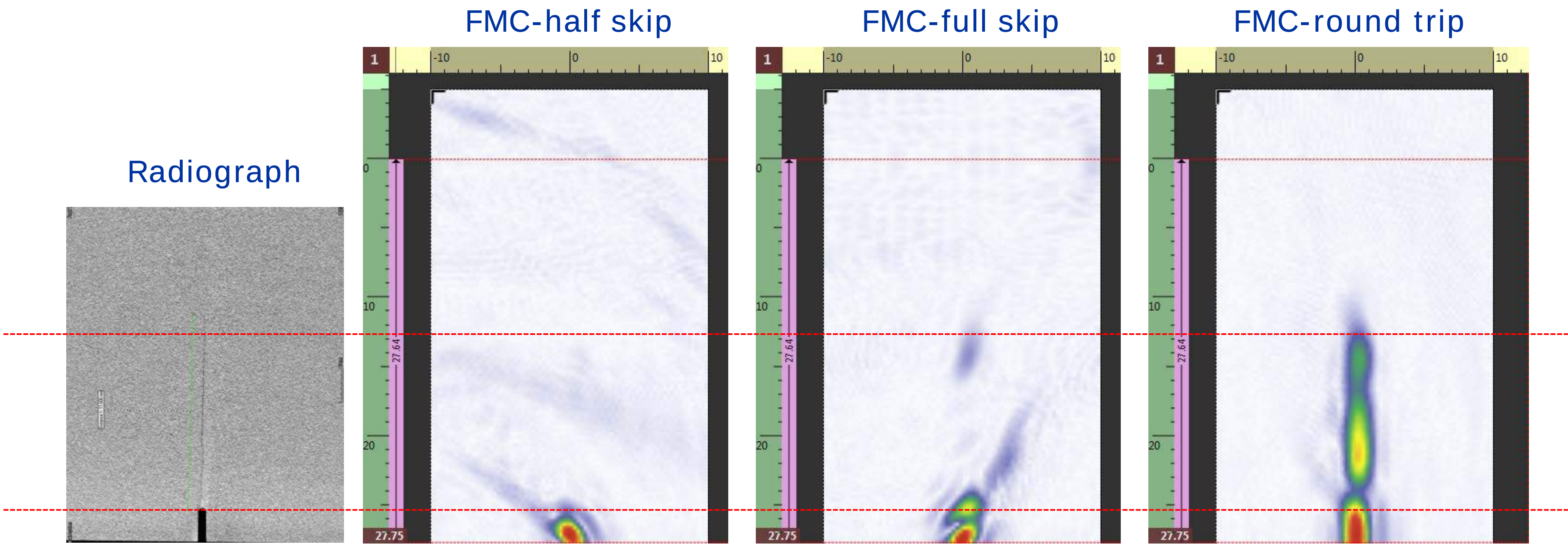
Weld inspection



Double V-Butt weld

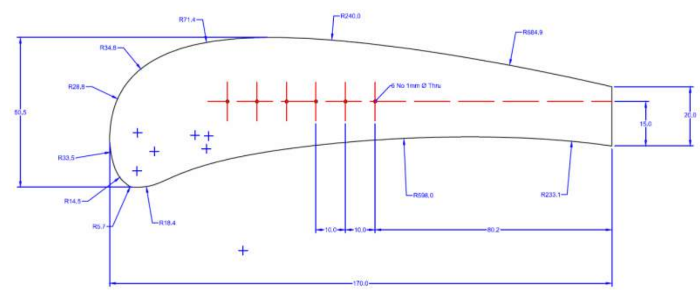
32 element probe + wedge

Self Tandem



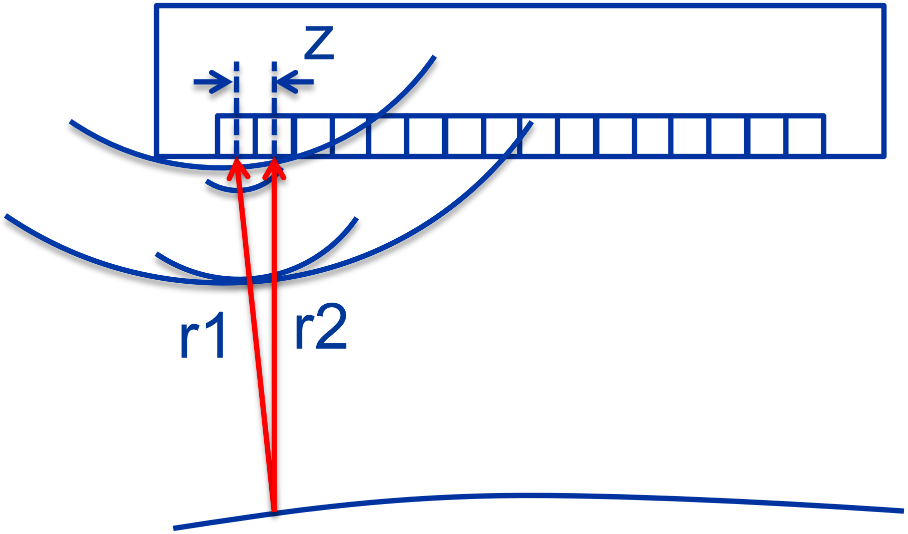
Modified algorithm to allow for imaging for vertical flaws that would be missed with traditional FMC (real-time)

Complex geometry

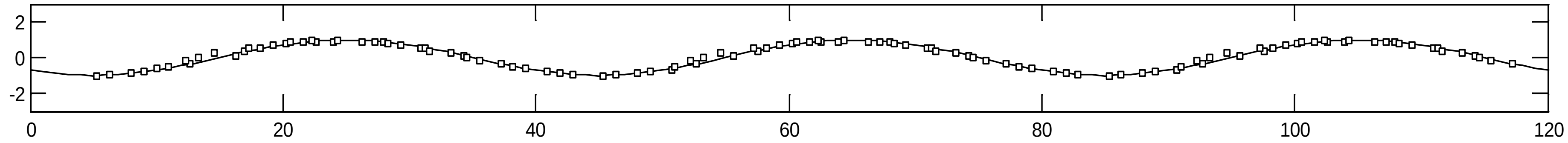


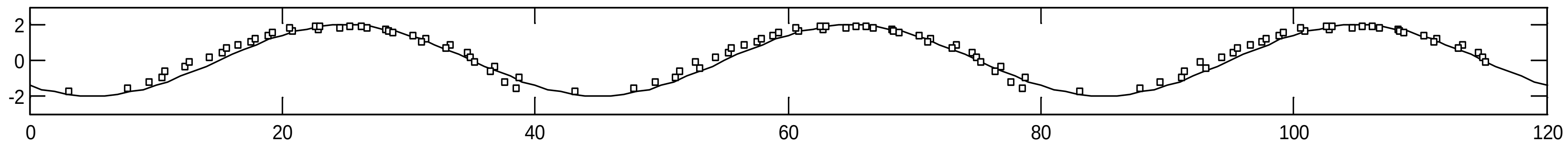
Interface detection

- Many components have curved surfaces
- Need to compensate for non-zero degree angles formed at ends of large arrays
  - Pulse on element 1
  - Receive on elements 1 & 2
  - Triangulate location of
  - reflector from
  - r1, r2 and z



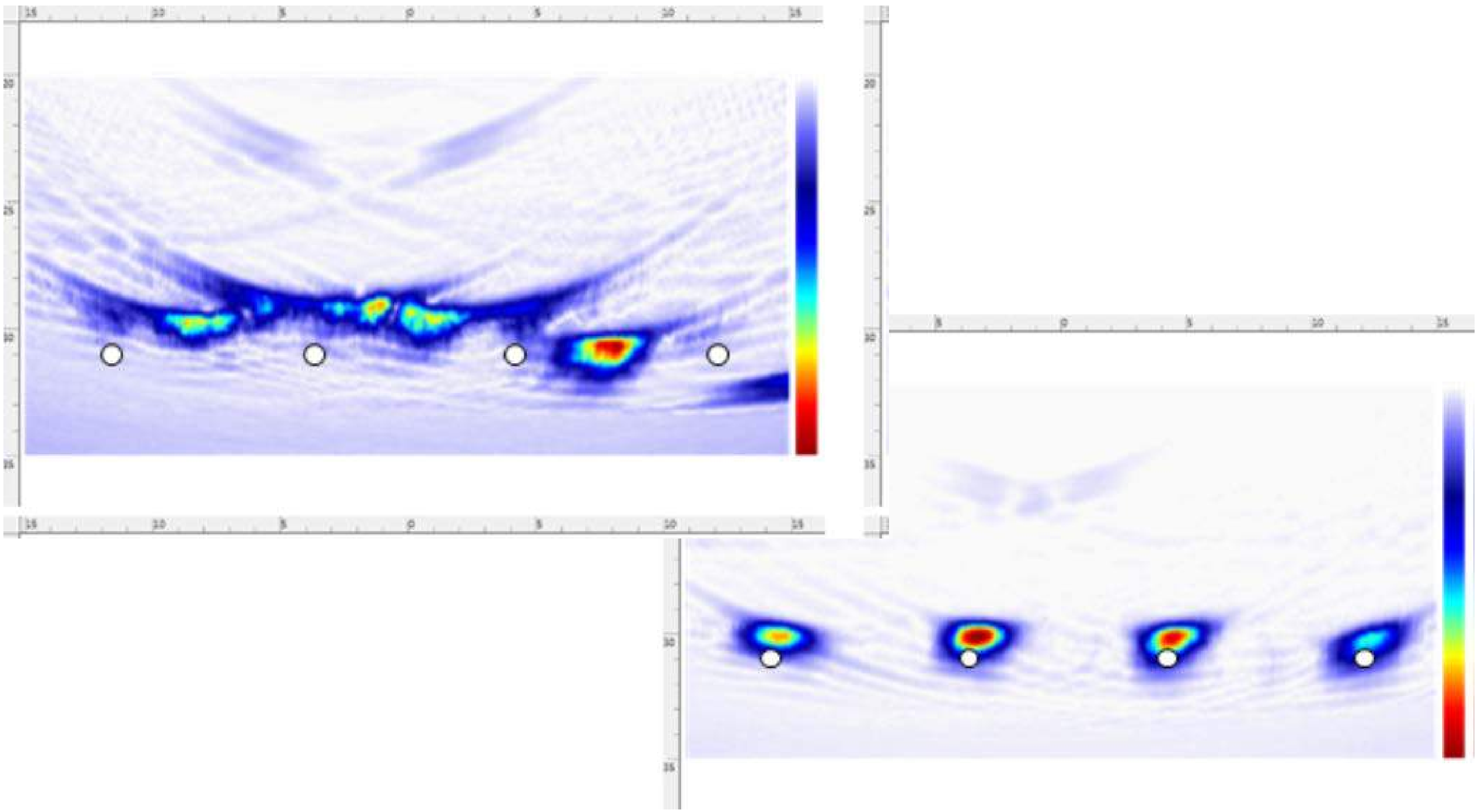
Profile mapping





Profile of component is obtained from FMC data by using first arrival time and triangulation

Complex Geometry



Complex geometry

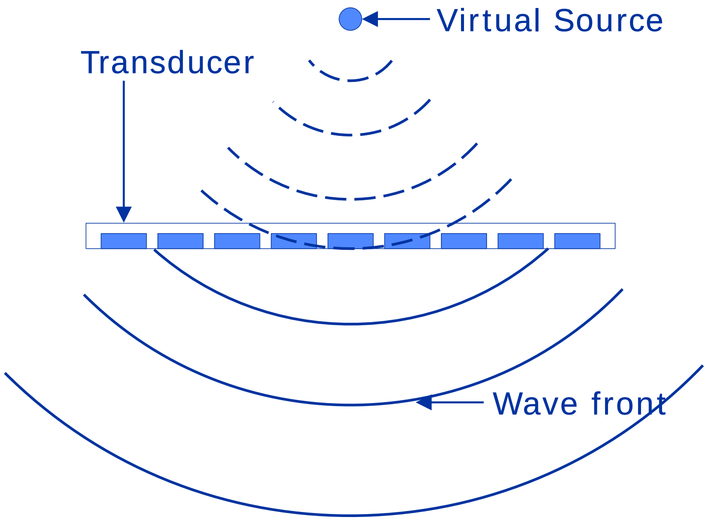
Virtual Source Aperture

VSA

Materials Joining and Engineering Technologies

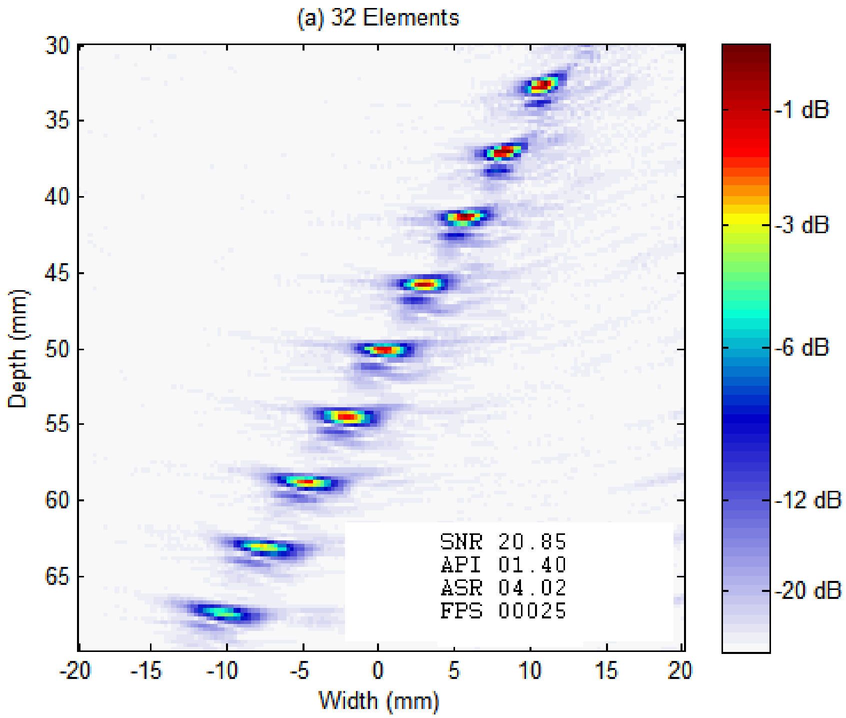
Virtual Source Aperture

- Transmits in phased array mode
- Receives in FMC mode
- Processed in same way as FMC acquired data

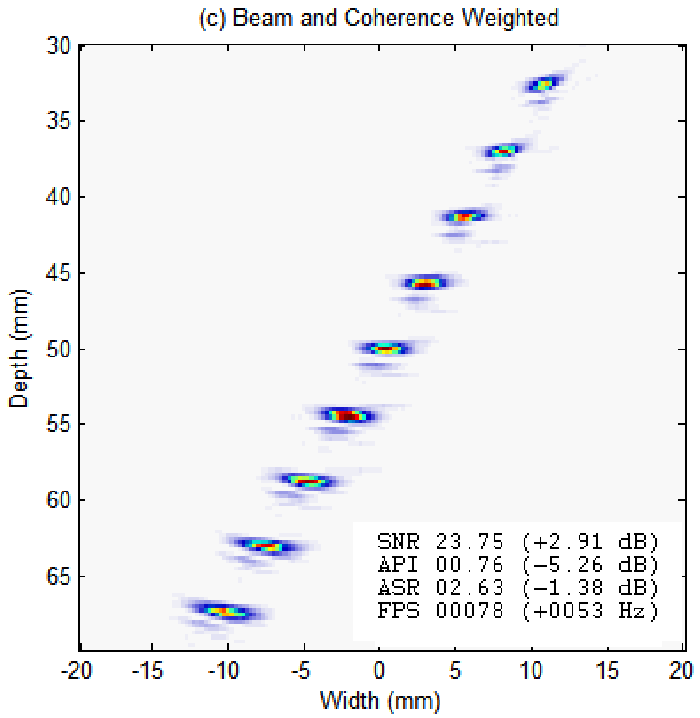


Virtual Source Aperture

FMC
Frame rate: 25Hz



VSA
Frame rate: 78Hz



Laser Welding of Cu and Al for Battery Interconnects

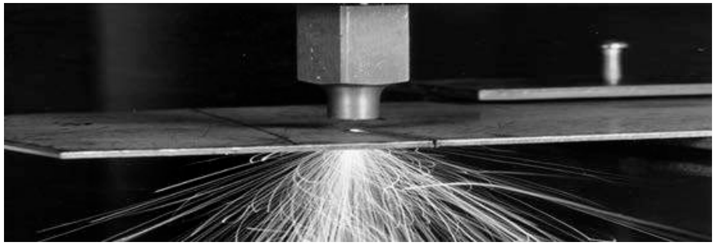
Dr Jon Blackburn

Materials Joining and Engineering Technologies

Presentation Overview

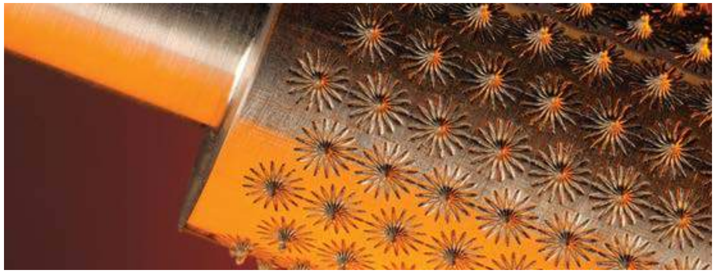
- TWI's laser materials processing activities
- Industrial requirements for battery interconnects
- Challenges when laser welding
- Approaches developed at TWI
  - Dual wavelength laser processing
  - Tailored energy distribution welding - scanner
  - Laser welding of Cu and Al foils – scanner
- Case Study
- Summary

Laser Materials Processing at TWI



1967 First ever gas assisted CO_2 laser cut

2004 Development of Seal Segment repair procedures for Rolls-Royce Trent Engines



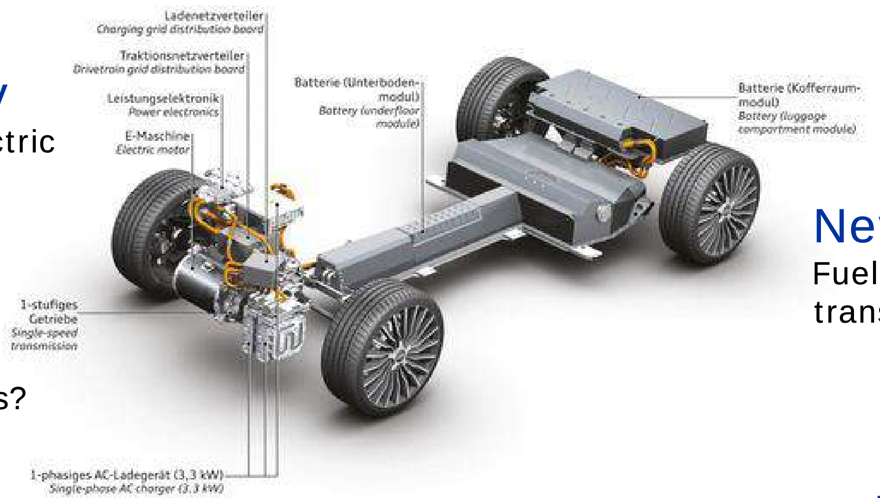
2007 Laser Surfi-Sculpt® - first demonstration

- ~ 45 years of history in laser processing
- ~30 staff working on laser processing
  - Joining, cutting, surfacing, additive
- Complemented by TWI experience in materials and integrity
- State-of-the-art facilities
  - R&D
  - Applications development
  - Training
  - Tech transfer activities
- Working with end-users
  - Transport, power, medical, oil & gas
- Majority of work is confidential

Laser Welding Battery Interconnects

Reliability
Break down? Motor life, repairability

Power technology
Fossil fuel, hydrogen, electric
Hybrid, other?



New infrastructure
Fuelling, home charge, power transfer, safety

Environmental
CO_2, other waste products?

Battery technology
Green batteries, charging time

Sustainable production
Environmental cost of production, rare earth metals, mining, political sensitivity

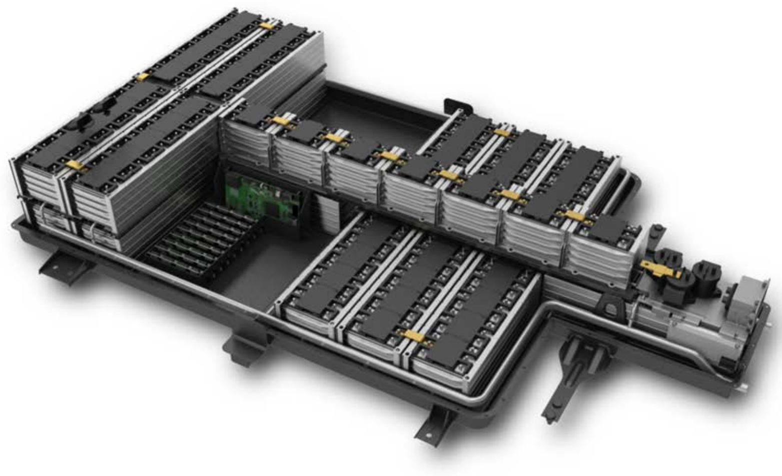
Cost
Transport for the people

New vehicle architecture
New power train = new layout.
Present cars are designed around the internal combustion engine

Performance
Range, speed efficiency

Battery Module Units

- 12 battery cells connected to form a battery module unit
- Materials: Copper (CU-ETP), Aluminium (1xxx, 3xxx, 6xxx)
- Joints
  - Lap joint configuration
  - Al-Al, Al-Cu, Cu-Al, Cu-Cu
  - Penetration depth of 1-3mm, weld width at interface >0.8mm.
- Production speeds >4m/min

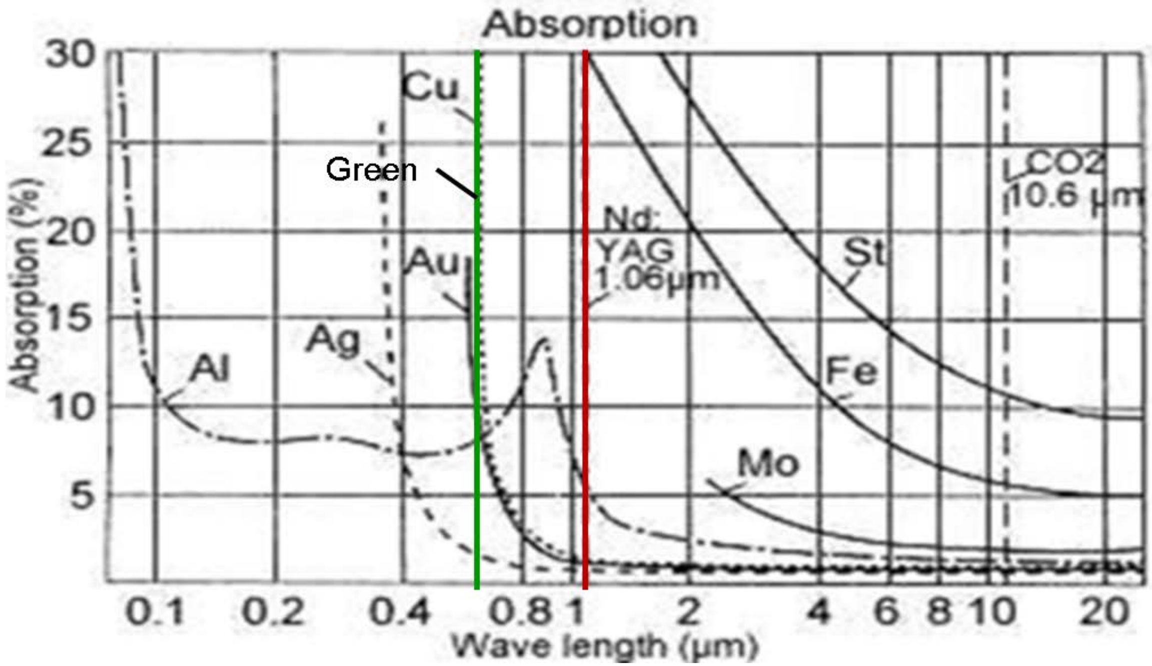


Current Joining Techniques

- Adhesive bonding
  - Slow, surface preparation needed, electrical conductivity
- Mechanical fastening
  - Additional weight
- Why laser welding?
  - Low total heat input
  - Remote
  - Ease of deployment
  - Ability to process complex shapes
  - High speed
  - etc

Challenge - Reflectivity

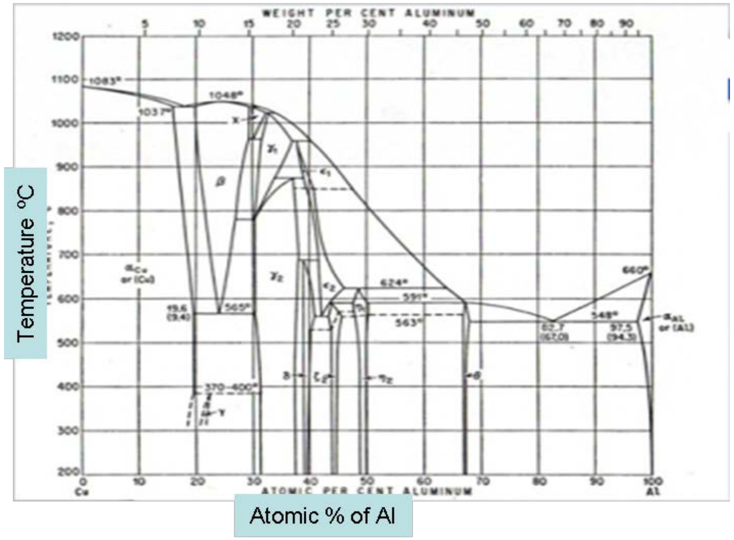
Relevant when Copper on top

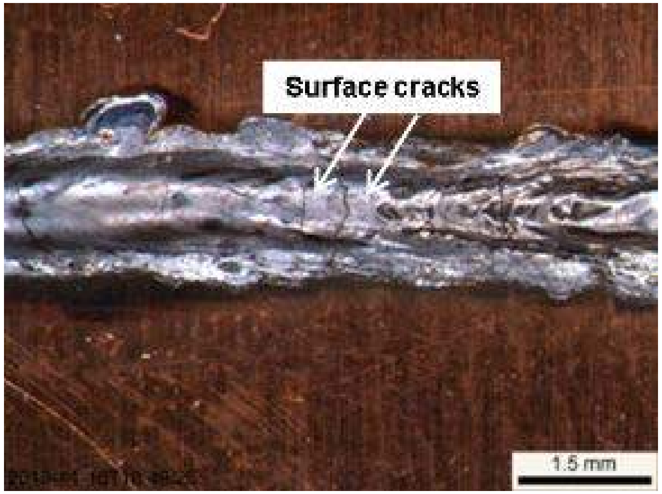


Unstable process in Cu-Cu lap weld, leading to Presence of melt ejections and blow holes

Challenge – Dissimilar Materials

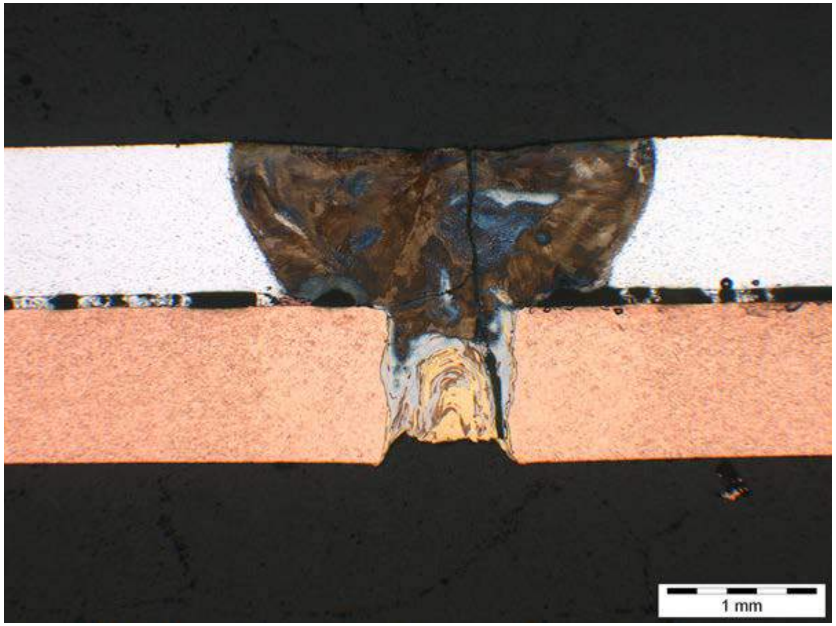
- Thermo-physical
  - CTEs - distortion
  - Melting points
  - Boiling points
  - Viscosity
  - etc
- Chemical compatibility
  - Brittle intermetallic phases, leading to fusion zone cracks

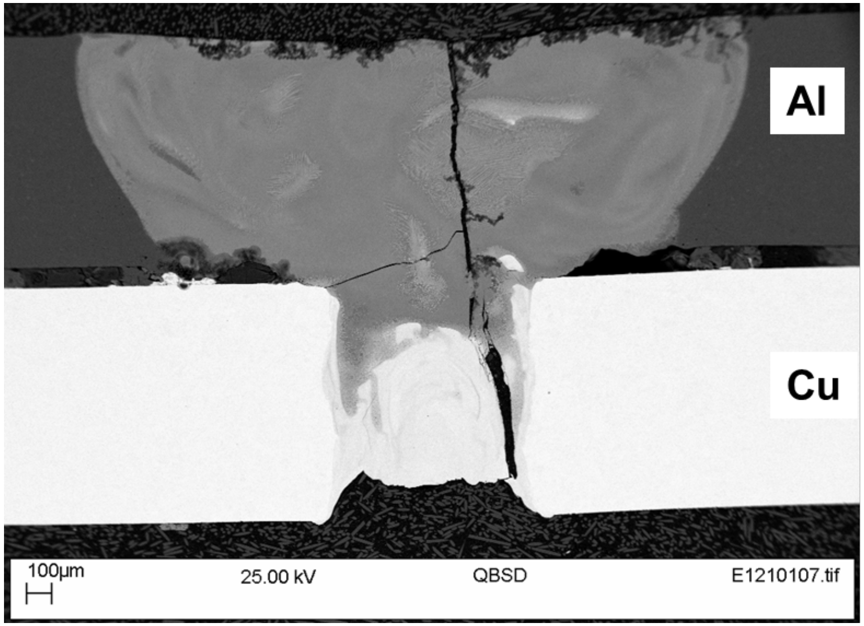




Challenge – Dissimilar Materials

Typical problems when laser welding Al-Cu





Al6061-CW004

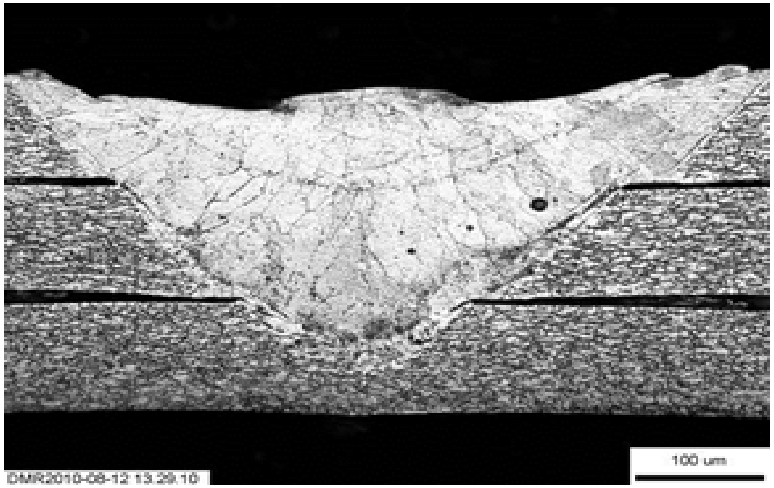
SEM analysis indicated crack initiated in the Cu rich phases in the weld root

Presentation Overview

- TWI's laser welding activities
- Industrial requirements for battery interconnects
- Challenges when laser welding
- Approaches developed at TWI
  - Dual wavelength laser processing
  - Tailored energy distribution welding
  - Laser welding of thin foils
- Summary

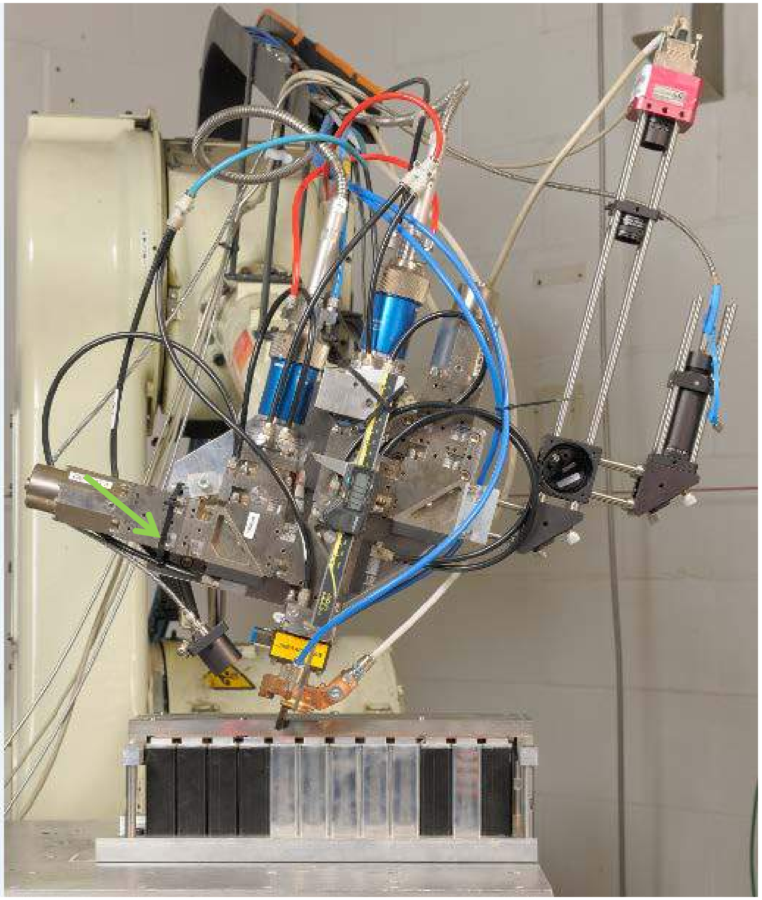
Dual Wavelength Processing

- Pulsed and continuous-wave green lasers available
  - Increased suitability for Cu processing due to lower reflectivity
  - Penetration depths ~ 2mm possible
  - But… low average powers
  - But… low productivity
- Combined wavelength processing
  - Use green to initiate melting
  - Remaining energy from IR source (fibre/disc)



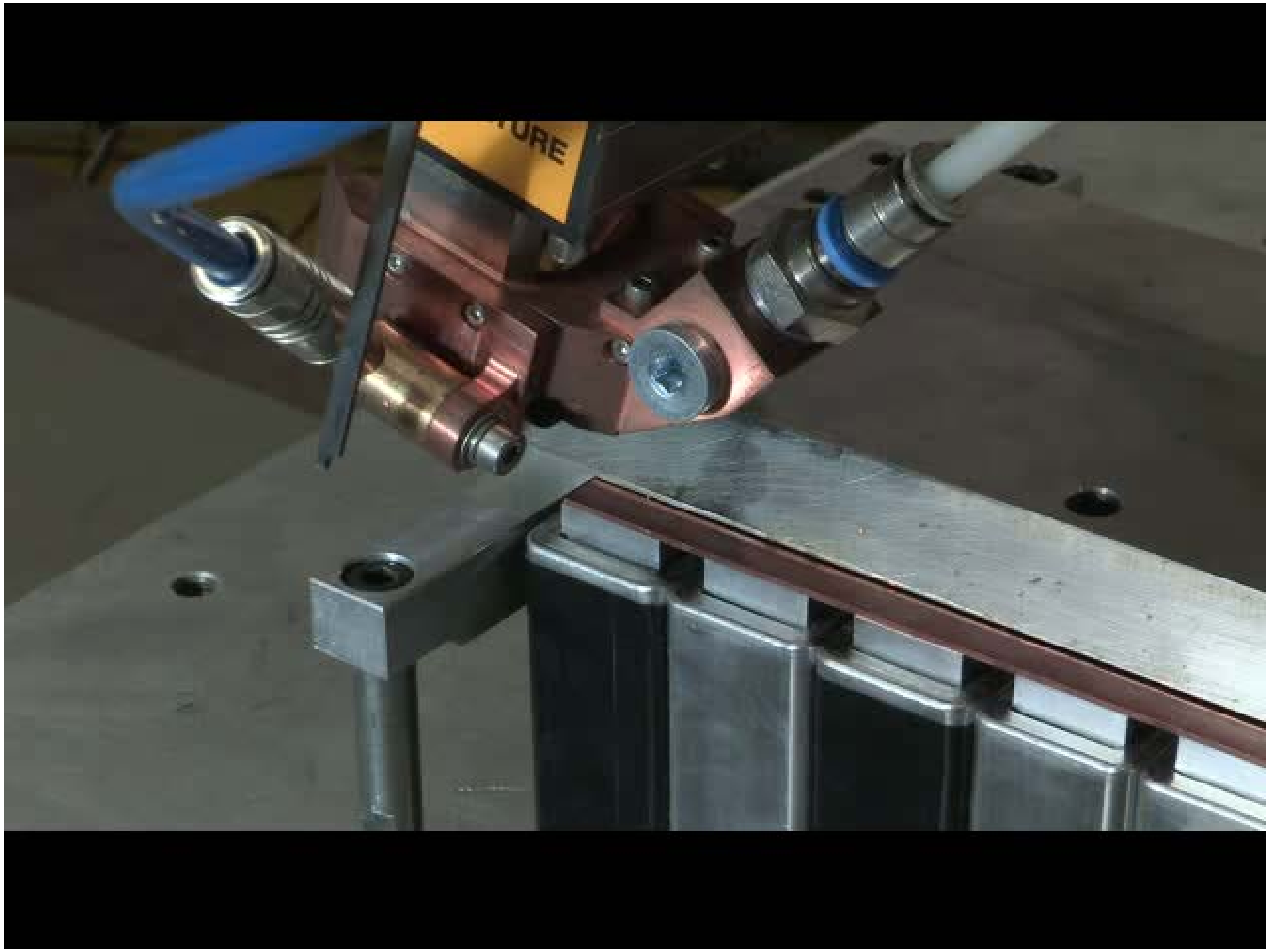
Pulsed laser welding in Cu - 250μm penetration

Dual Wavelength Platform



Precitec dual wavelength processing head integrated with the pulsed green laser and Yb-fibre laser

Dual Wavelength Platform



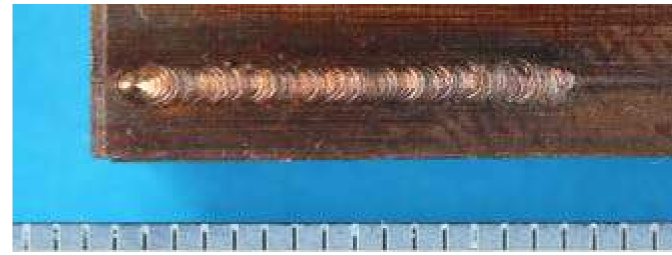
TWI

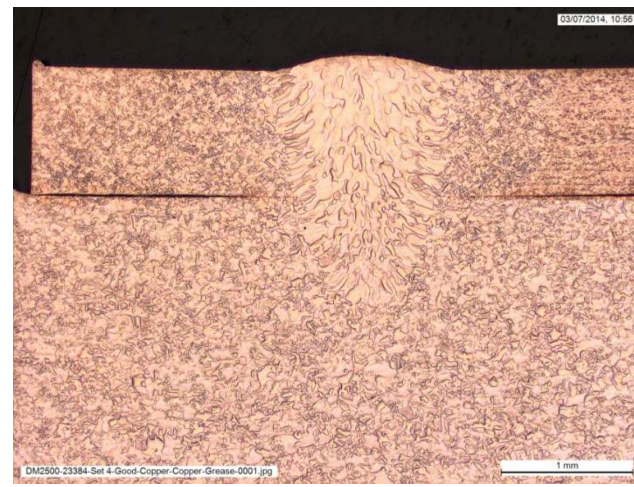
VOLKSWAGEN
AKTIENGESELLSCHAFT

PRECITEC

Cu-Cu with Dual Wavelength Platform

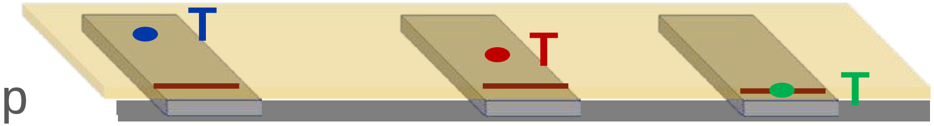
- Weld quality of the quasi-optimised condition assessed against ISO 13919-2:
- No cracks observed
- No surface blow holes and melt ejections were detected
- Interface weld width was greater than 0.8mm.
- Subsurface porosity was not observed

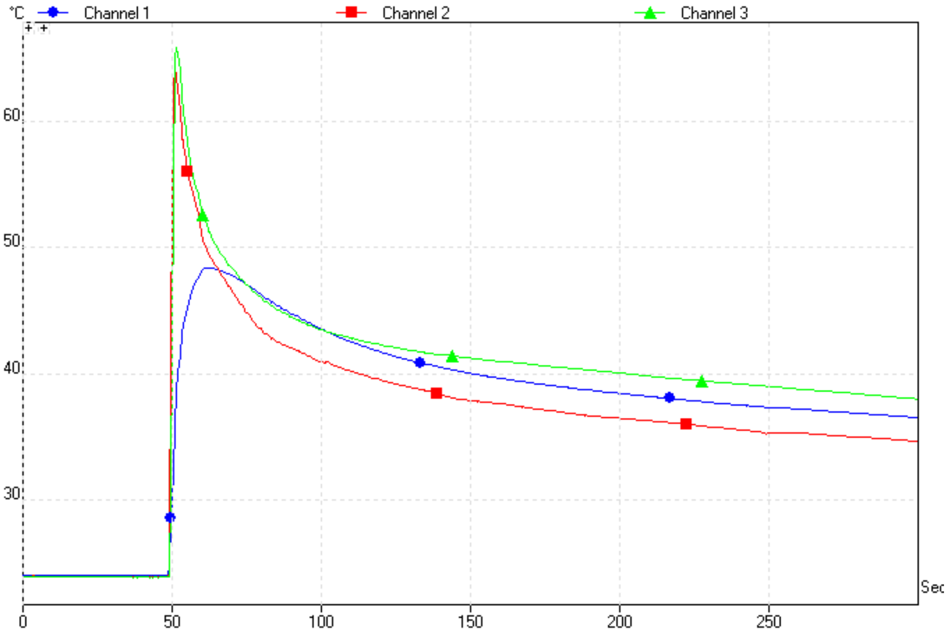




Temperature Effects

- Cell chemistry
  - Breakdown at high temp
- Temperature measured
  - Thermocouples
  - Three points under cell terminals
- Max temp observed <70degC
- Within acceptable limits

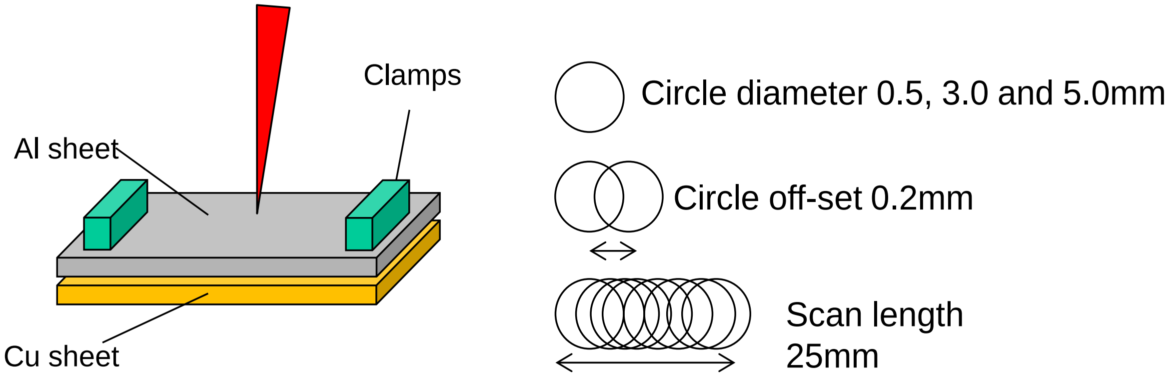




Tailored Energy Distribution

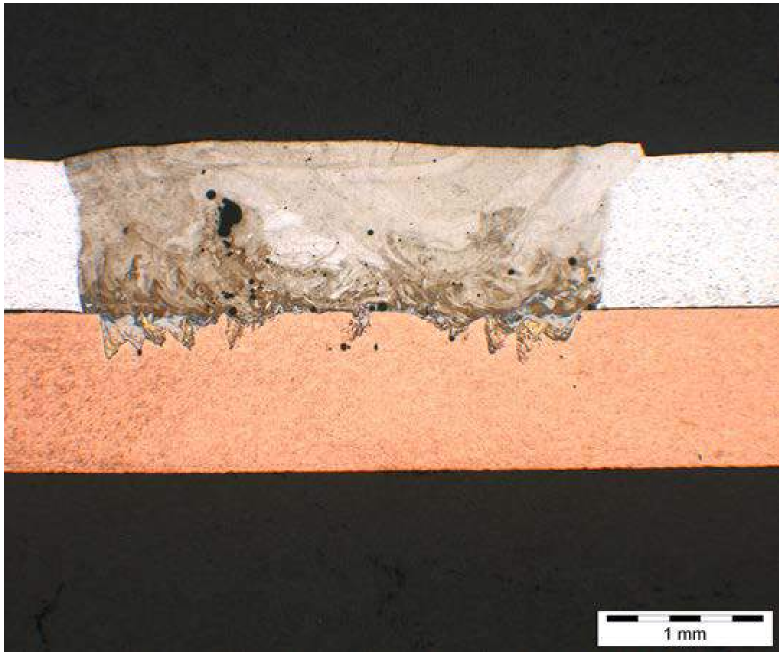
- Present applications use simple energy distributions
  - Gaussian, top-hat
  - Annular
  - Twin-spot
  - Lines
- Laser beam scanners
  - Possibility to tailor temporal energy distribution to joint requirements
  - Limitless possibilities
- Similarities to electron beam
  - Electro-magnetic deflection

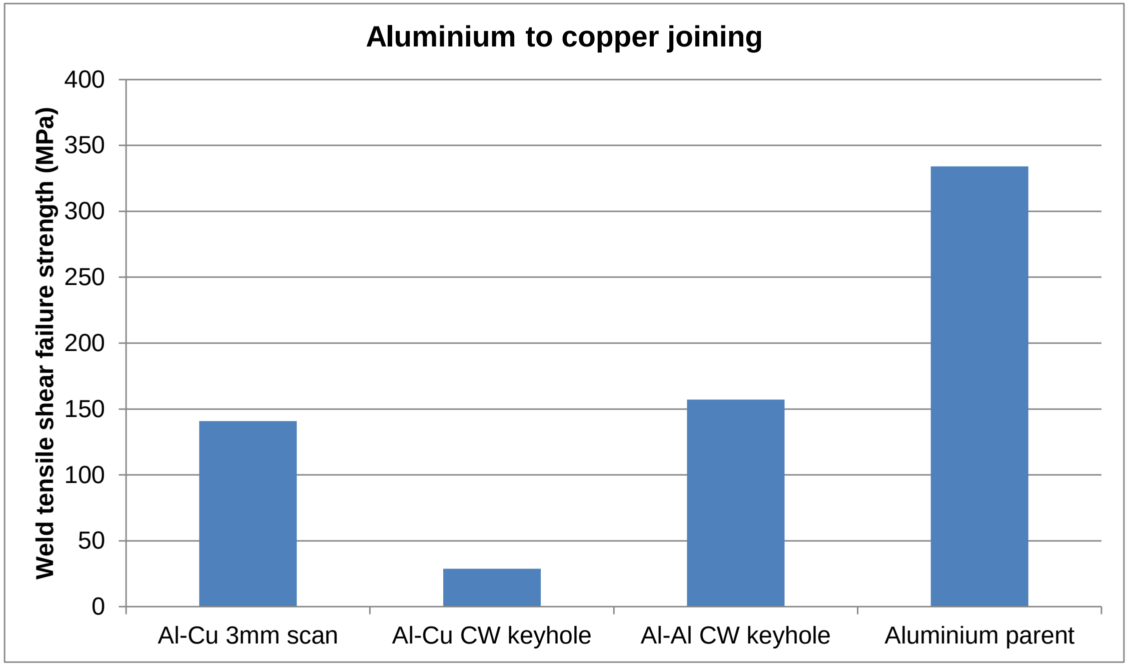
Tailored Energy Distribution for Al-Cu



- Parameters developed to:
  - Minimise penetration into underlying metal, thereby limiting potential for Intermetallic phases
  - To control heat input into the workpiece
  - To provide a ‘stirring’ action and thereby disperse deleterious intermetallic phases

Tailored Energy Distribution for Al-Cu

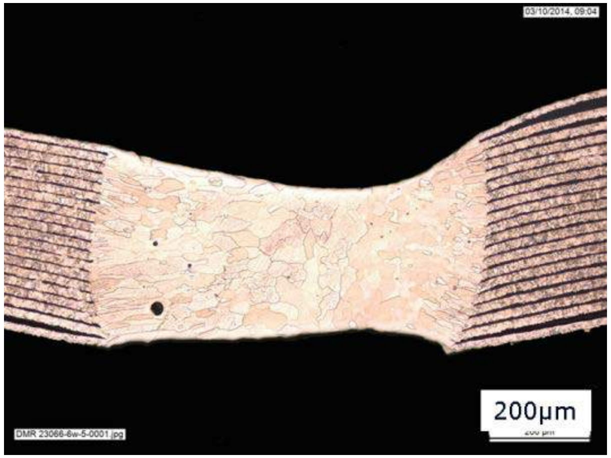




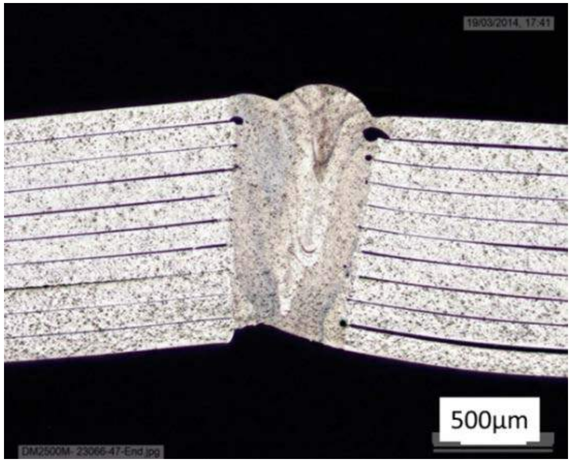
Resulting weld (transverse) cross-section and tensile shear strength of quasi-optimised laser weld in Al6061-CW004

Tailored Energy Distribution –Foils

Laser welding conditions for lap welding multi-foils of Al and Cu alloys



Single pass 20 lap-welded copper foils, each 17µm thick (electrical connection applications).

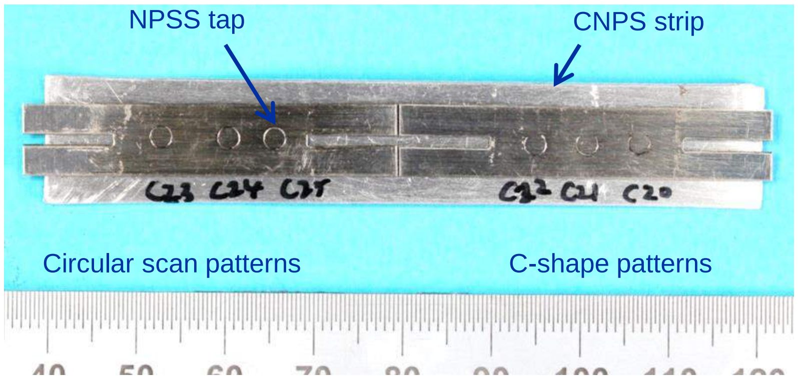


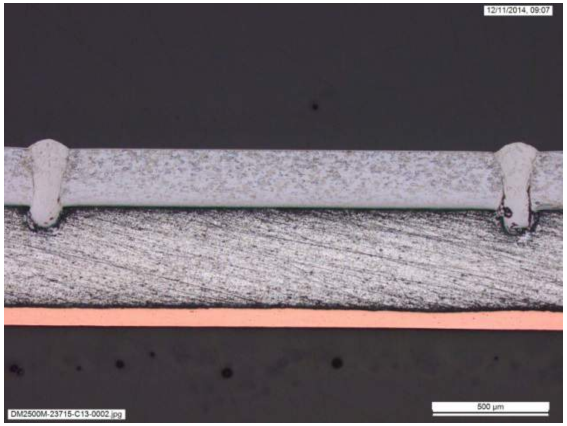
Single pass ten lap-welded Al 1050 foils, each 100µm thick (electrical connection applications).

Single pass 4 lap-welded copper foils, each 100µm thick (electrical connection applications).

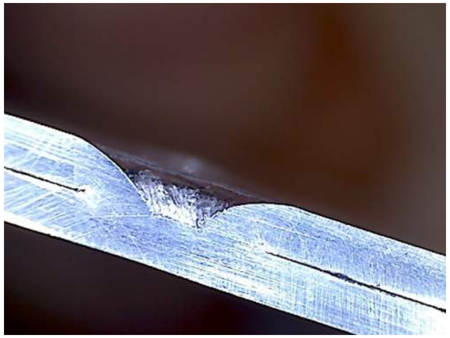
Case Study – Battery Terminal to Cell

- Overlap joining nickel plated steel to copper-nickel plated steel





- Edge welding (4mm hole diameter) of battery terminal to cell



Summary

- Industrial need for joining Cu-Al and Cu-Cu
- Laser welding has huge potential
  - Challenges: reflectivity, intermetallic phases
- Tailored energy distribution for Al-Cu
  - Temporal modification of laser energy

- Dual wavelength processing
  - Spatial modification of laser energy

Further Information

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E-mail: jon.blackburn@twi.co.uk

TWI

IntACom

Development of a Fast Inspection System for Complex Geometry

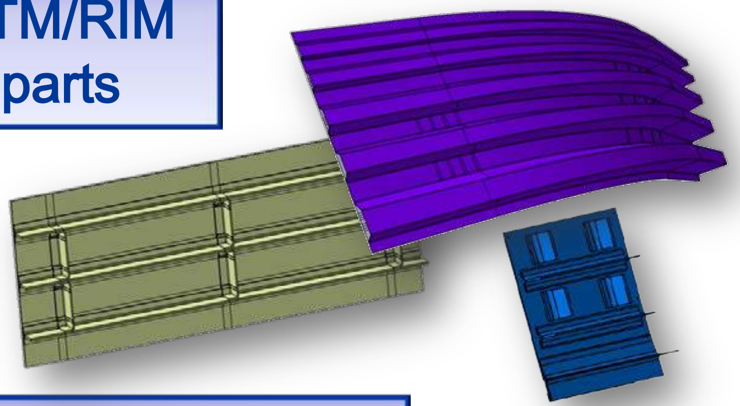
Ian Cooper

Materials Joining and Engineering Technologies

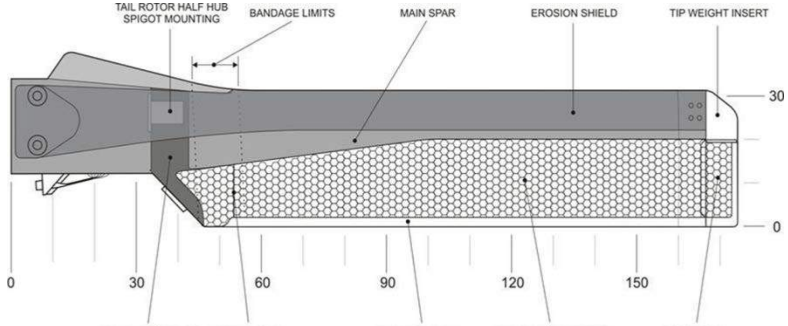
Areas of rapid development

Composites

RTM/RIM parts



Hybrid structures



Additive Manufacture

Laser Metal Deposition

- Powder Bed
- Blown Powder

EB Wire Deposition

Friction welding

- FSW
- Rotary
- Linear

The IntA*COM* Programme

- The IntA***COM*** programme is a series of JIP projects currently funded by Rolls-Royce, GKN , Bombardier, TWI and Welsh Government aimed at improving the speed of inspection of complex geometry components for the aerospace industry.

- IntA***COM*** 1 attracted £1.7m of funding and is now complete, resulting in a fully functioning robotic inspection cell able to inspect parts of virtually any shape

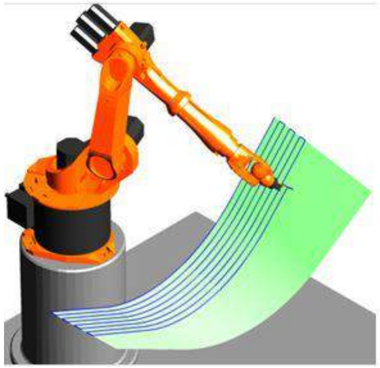
- IntA***COM*** 1a is now in progress with a value of £300k, adding further functionality to the cell, such as metrology for part location and identification and PAUT of thick section composites.

The IntA*COM* Programme 2

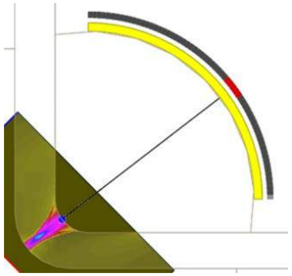
- IntA***COM*** 2 is in the proposal writing stage and has received input for the next phase of work from the existing partners. This will include large structures such as spars and wing covers, and the addition of FMC to the software.
- The success of the programme has attracted interest from additional partners, who have expressed keen interest in joining the programme, raising the potential value of the next phase to £2.6M.
- IntA***COM*** 3 is in the scoping phase and is expected to look at complex metal fabrications such as SPFDB and AM parts and remote inspection using robots.
- IntA***COM*** XL is also in scoping and will look at robotic inspection of very large structures such as WTBs, and GRP boat hulls.

Complex geometry - IntACOM

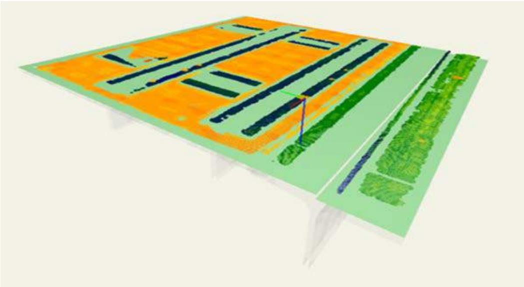
- Increased use of automation through advanced robotic manipulators



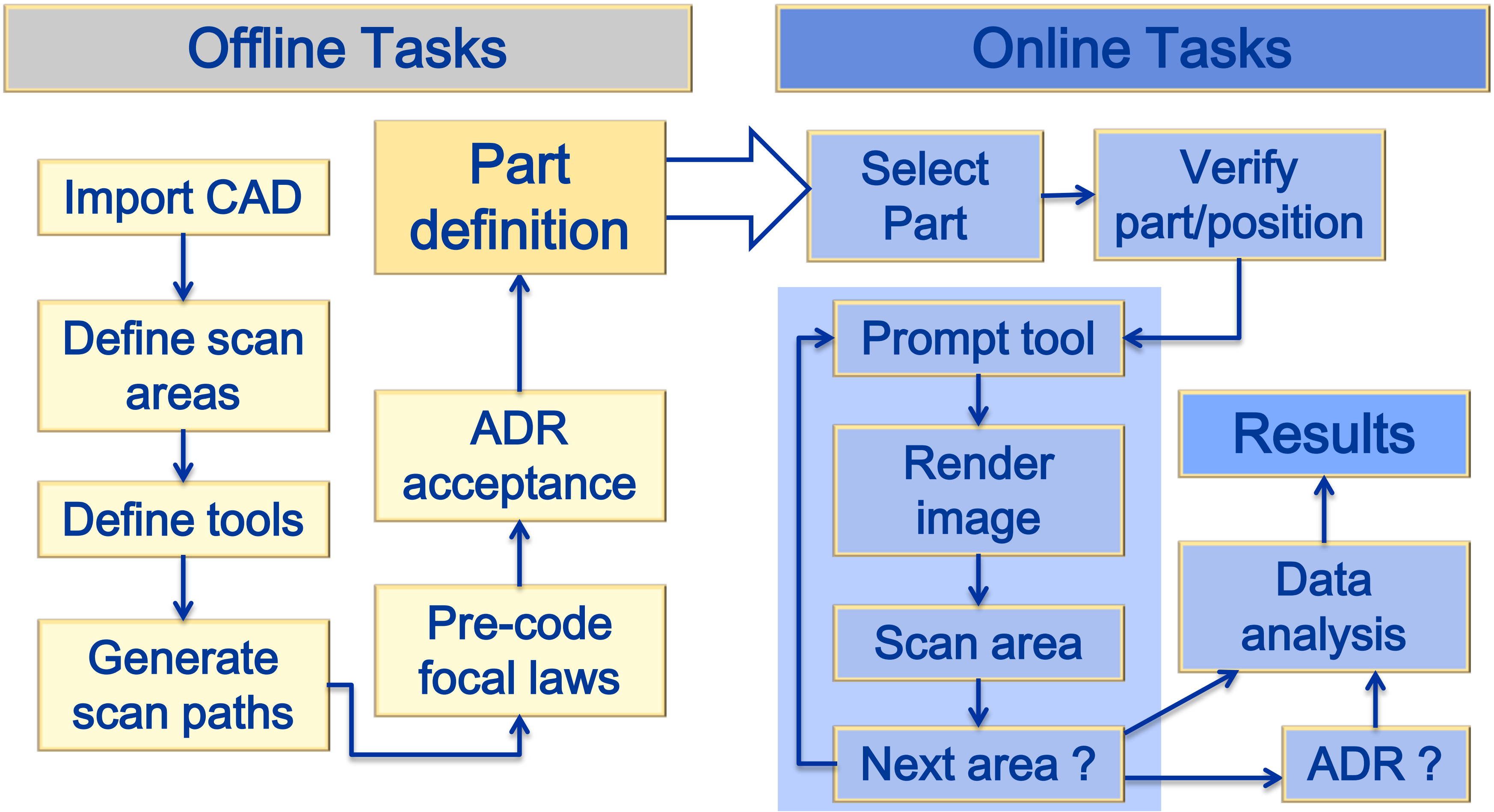
- Integration of advanced techniques such as PAUT and FMC



- Enhanced 3D imaging and analysis tools



Mode of operation



Robotic manipulator specification

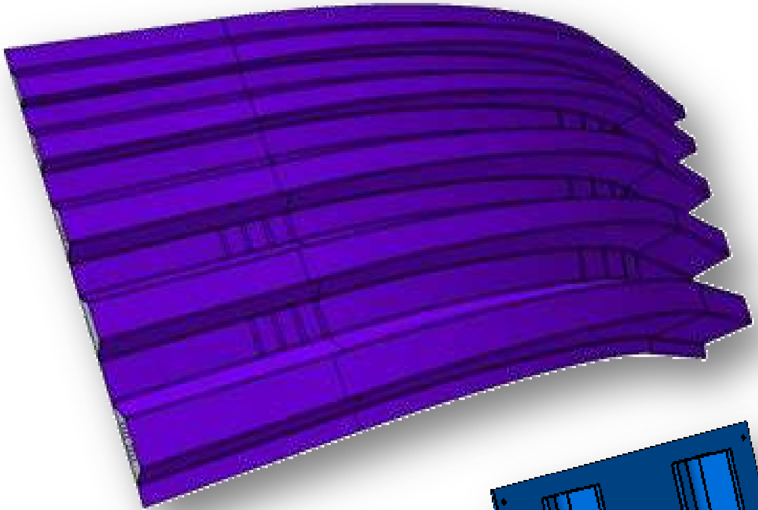
- Prototype must be able to inspect all areas of a 3x1x1m volume
- Fully scalable for production
- Able to stream positional data at high speed
- Work independently or cooperatively
- Waterproof to IP 65 (support water irrigation)
- Carry end effectors to support PAUT and other methods
- Programmable by user via CAD generated scripts and teach pendant

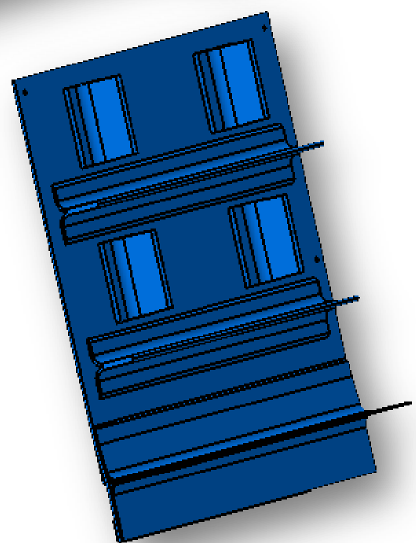
Selected 2 x KUKA KR16 L6-2

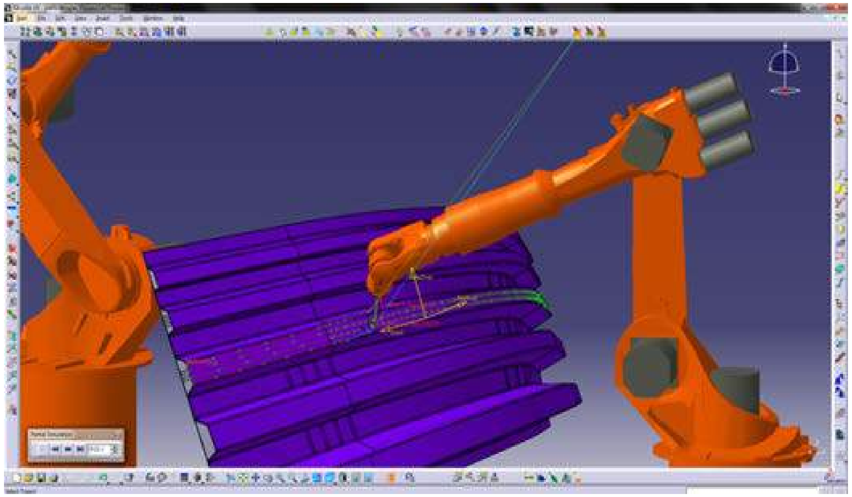
Payload : 6 kg

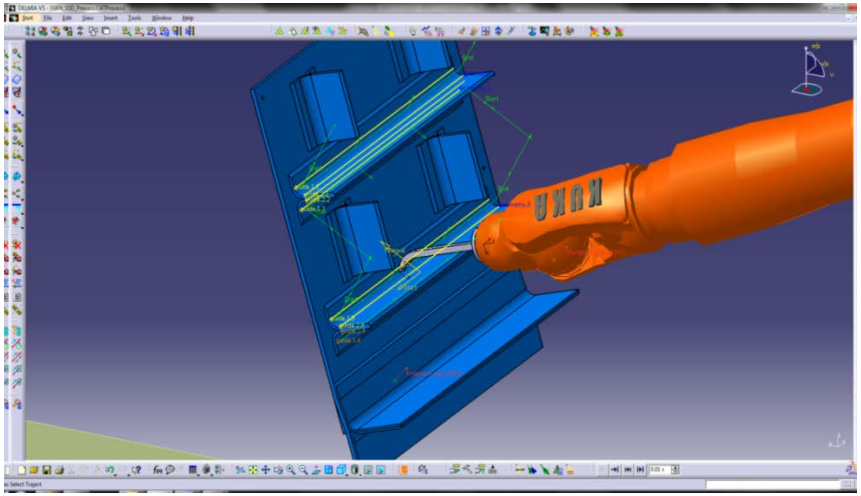
Repeatability:
<±0.05mm

Cenit FastSurf - Path planning

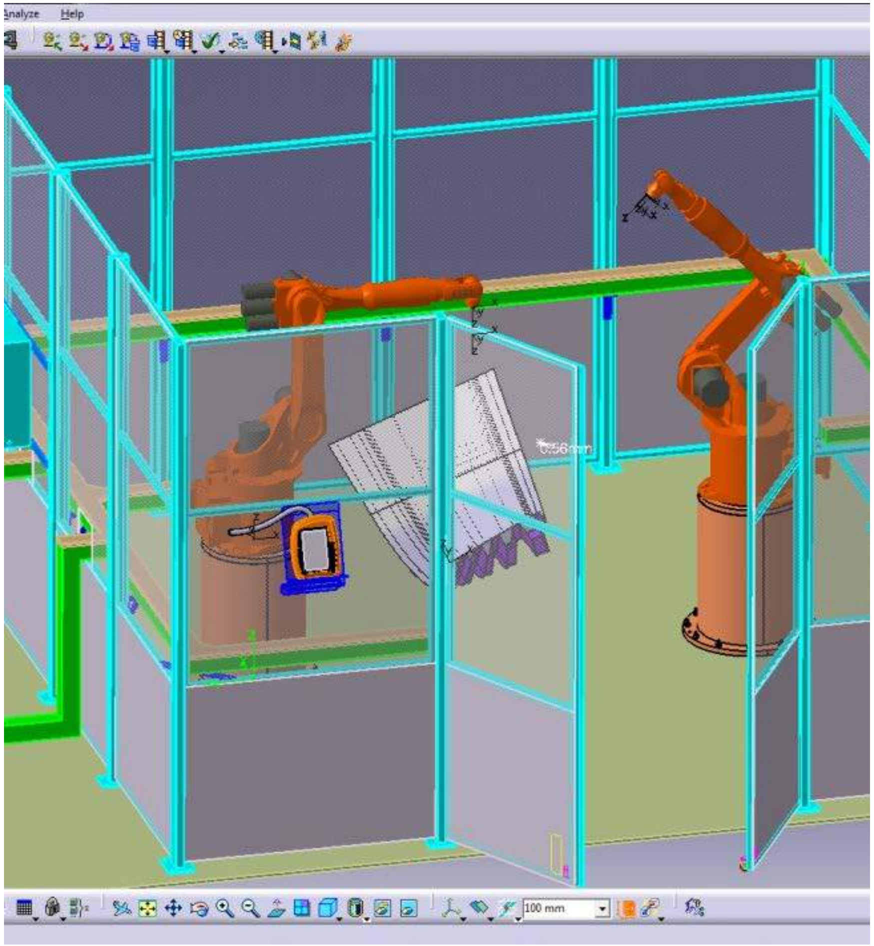


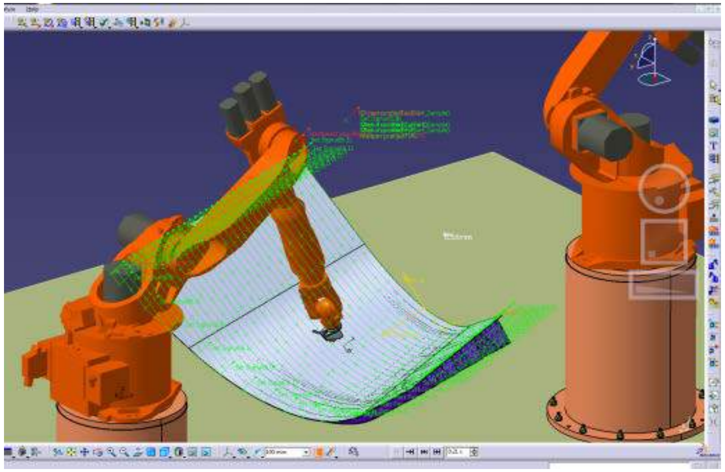




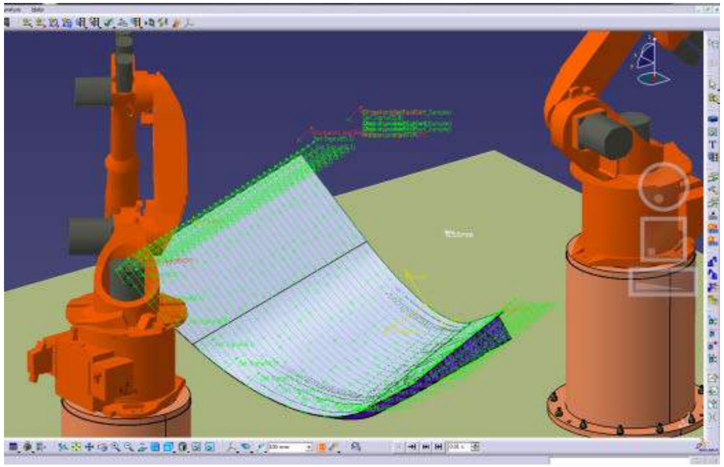


Cenit FastSurf - Path planning 2



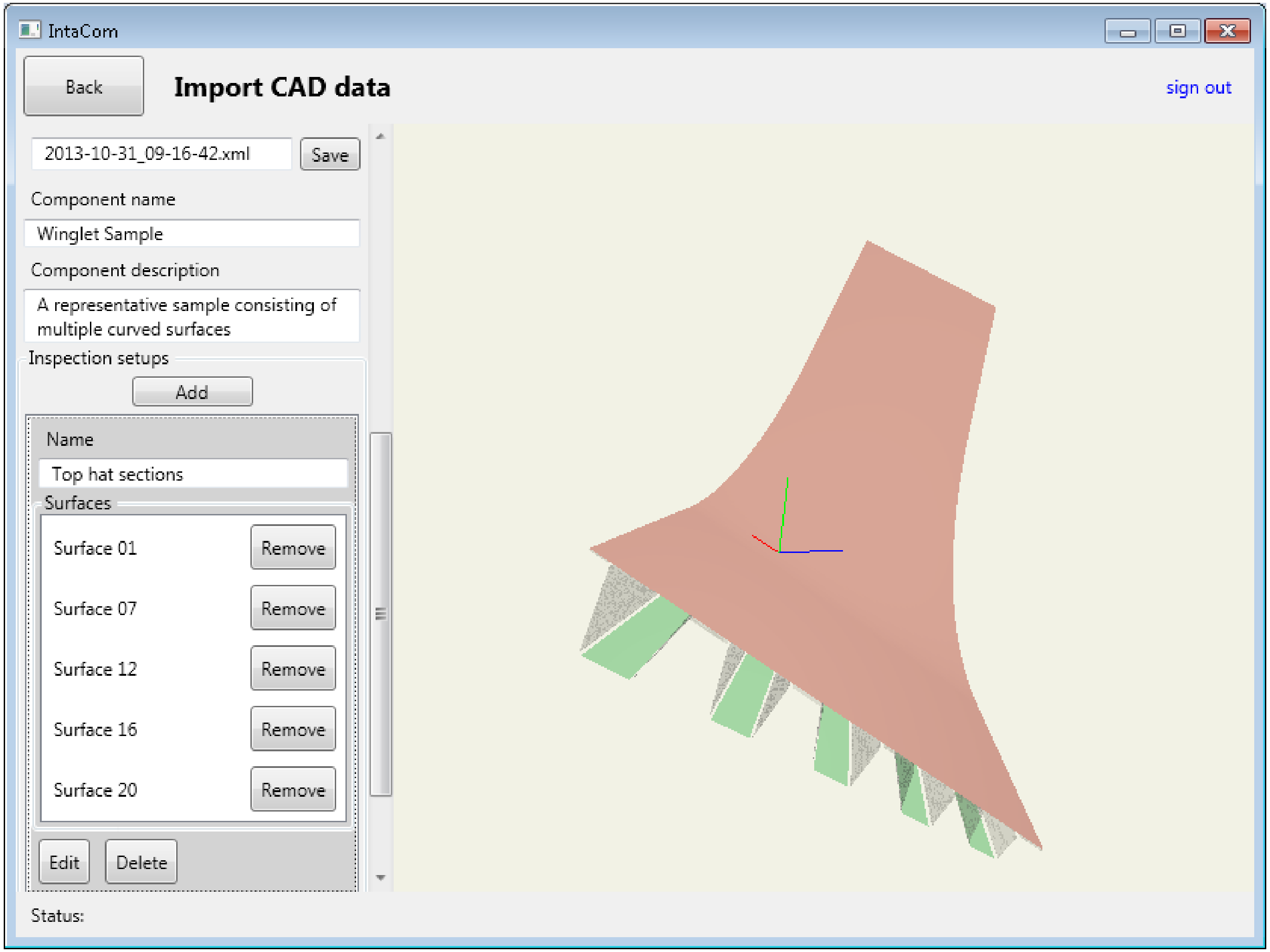


50% Progress

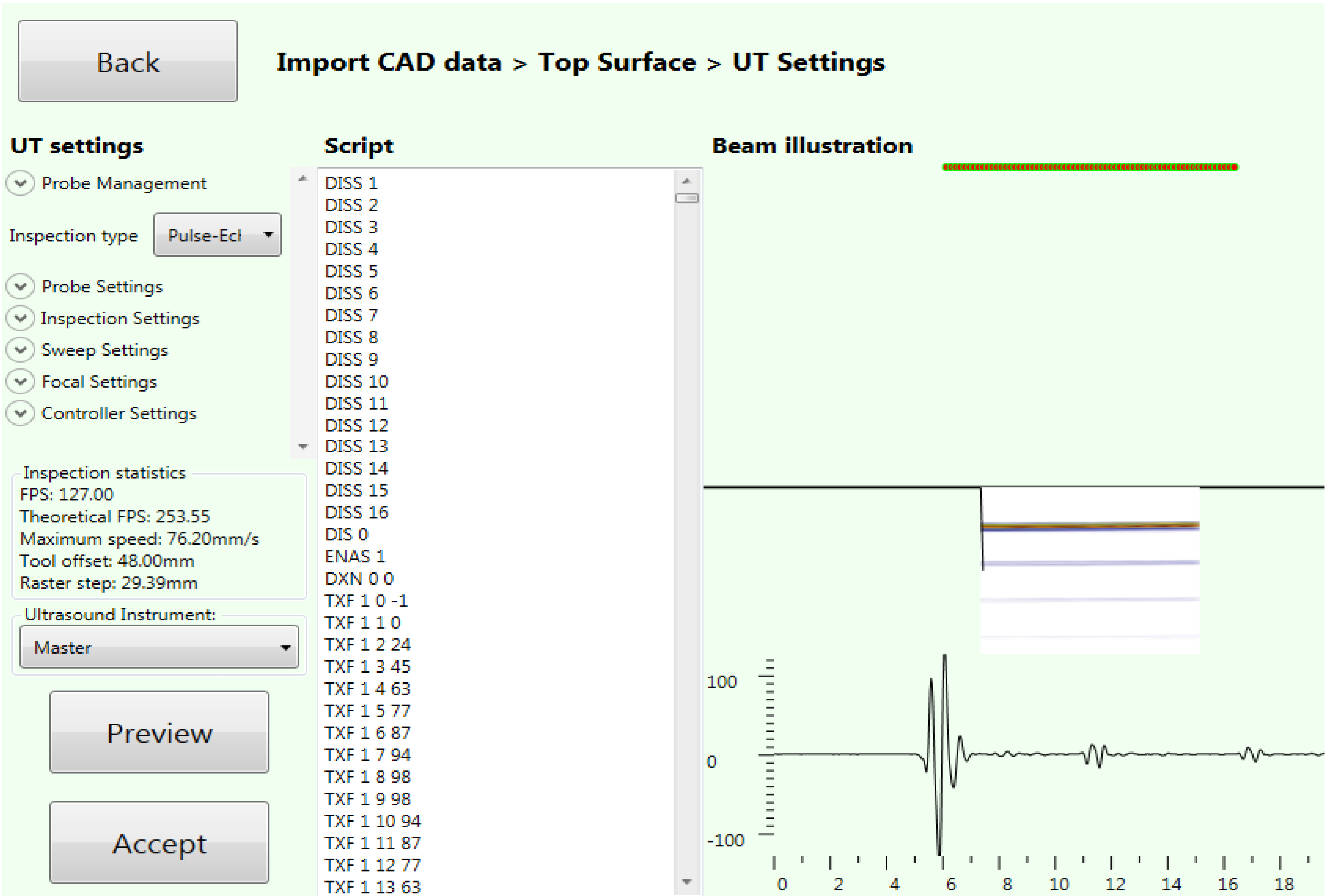


100% Progress

Scan surface selection



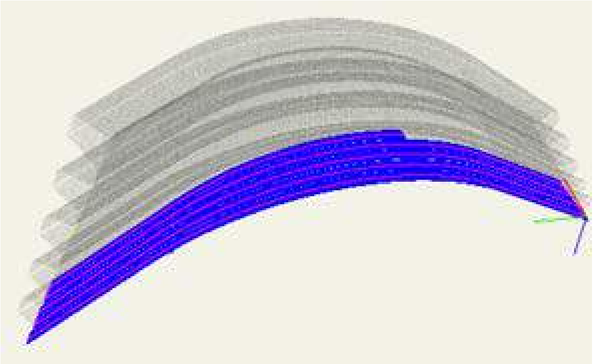
UT settings menu

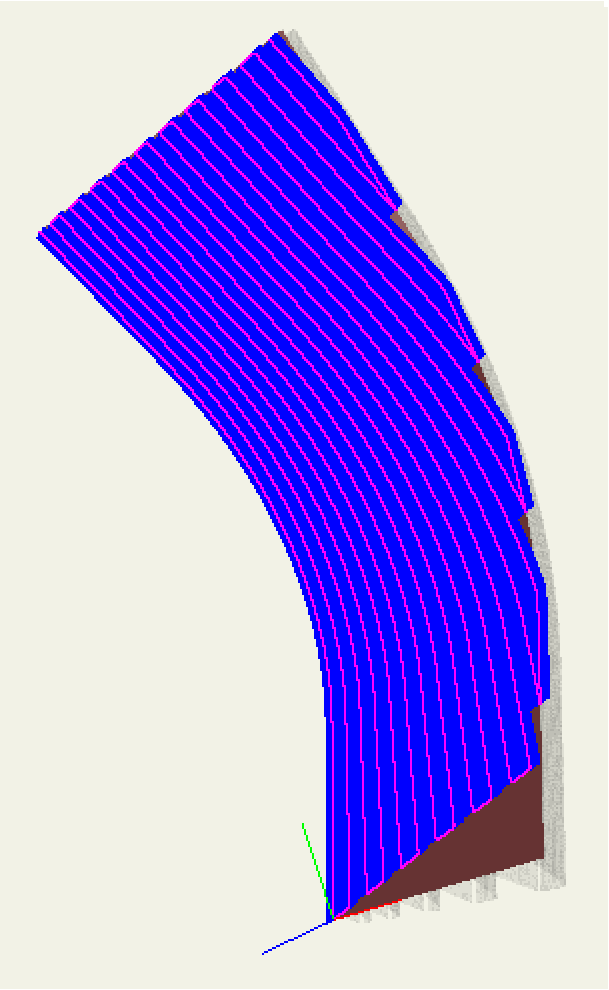


Scan overlay

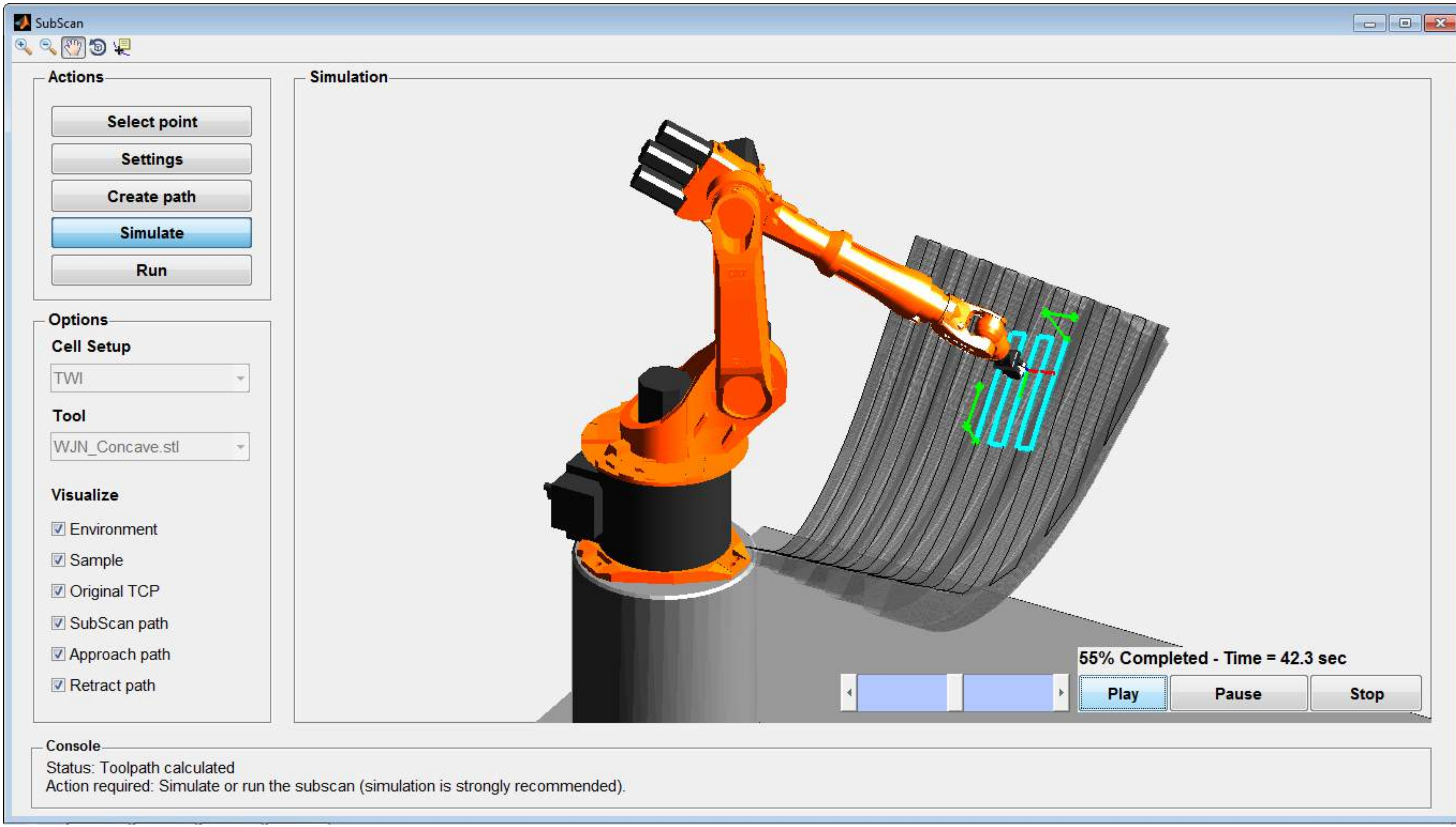
Real time feedback

- Blue: Ultrasound surface coverage
- Pink: TCP locations
  - Can be used to return to a previously scanned location

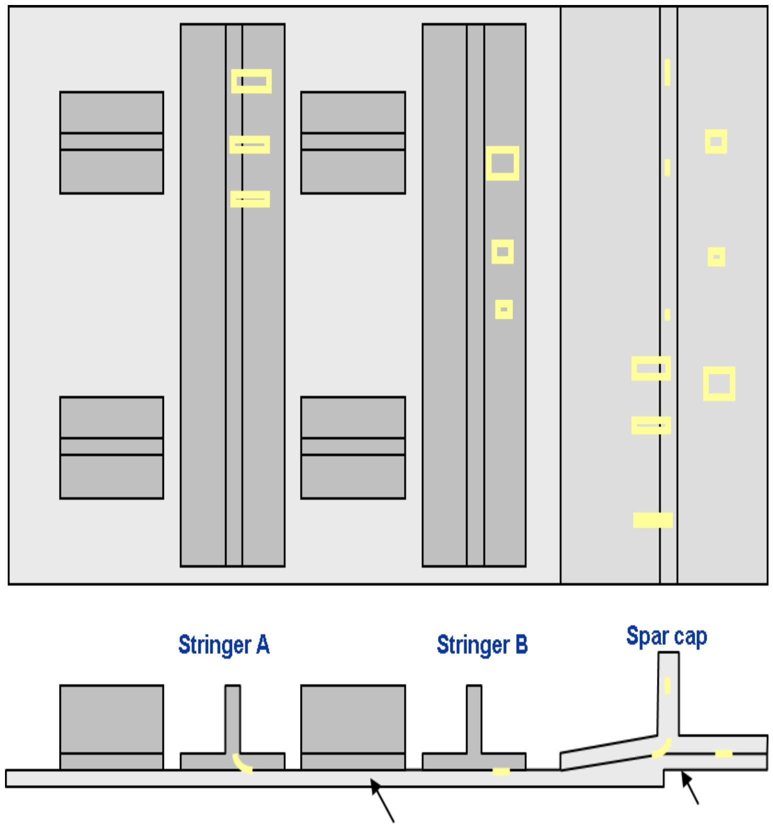




Returning to a point of interest



Wing skin panel



Scanned at 200mm/s

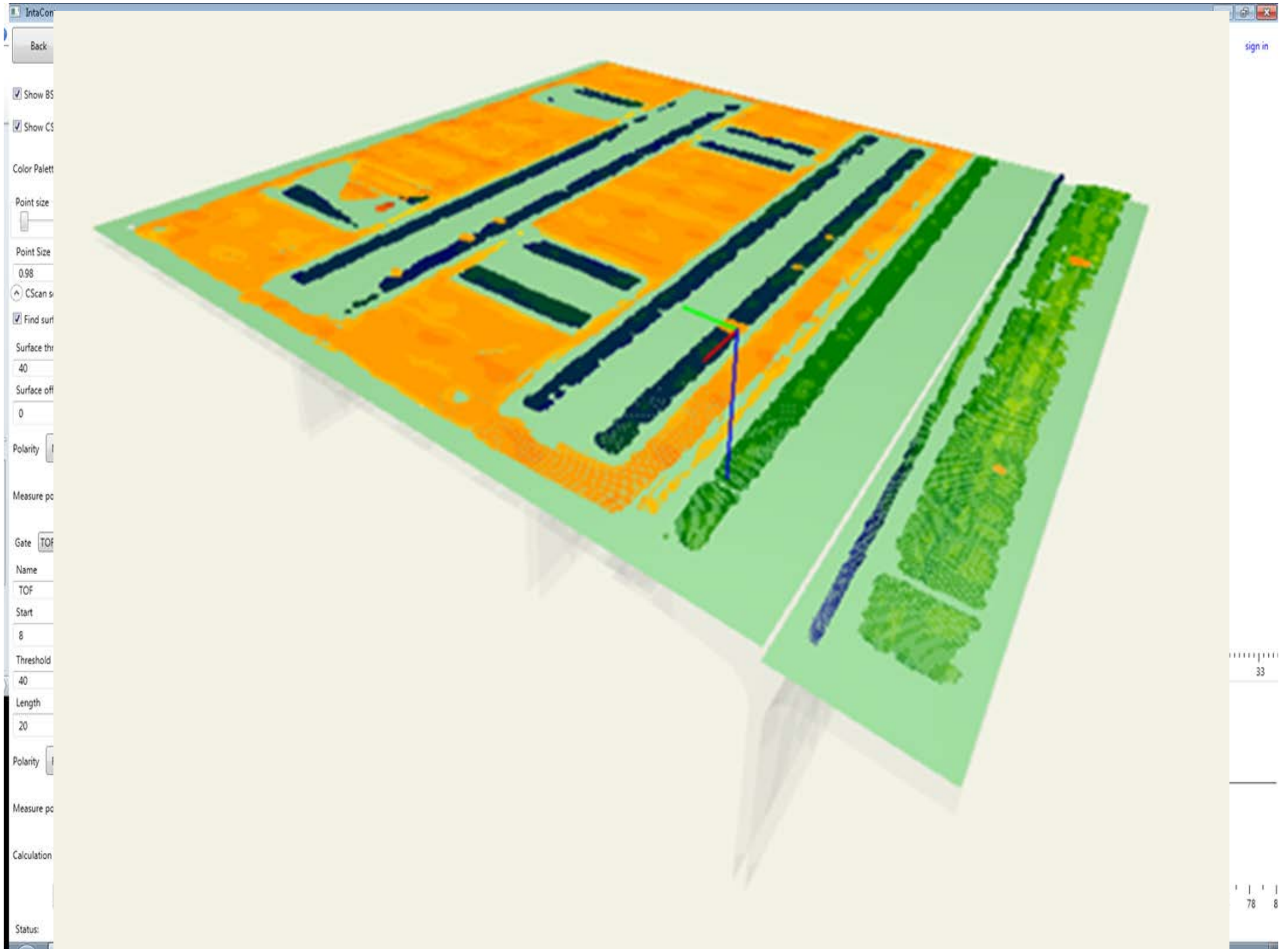
Tape insert flaws at various positions

Scanned at 200mm/s

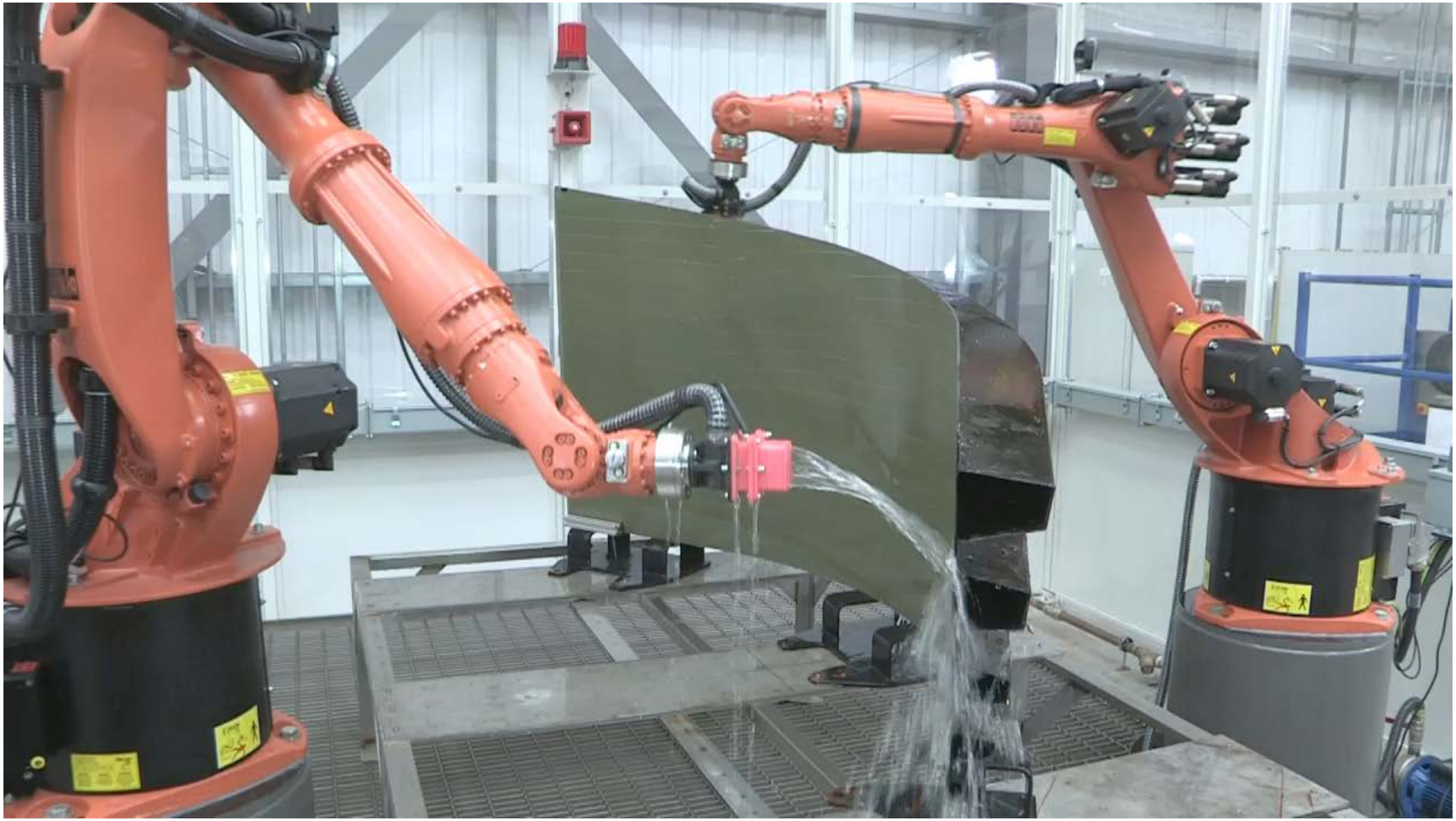
Analysis tools

Options

- Full 3D
- B-Scan
- A-Scan
- CAD
- TCP
- Cursors

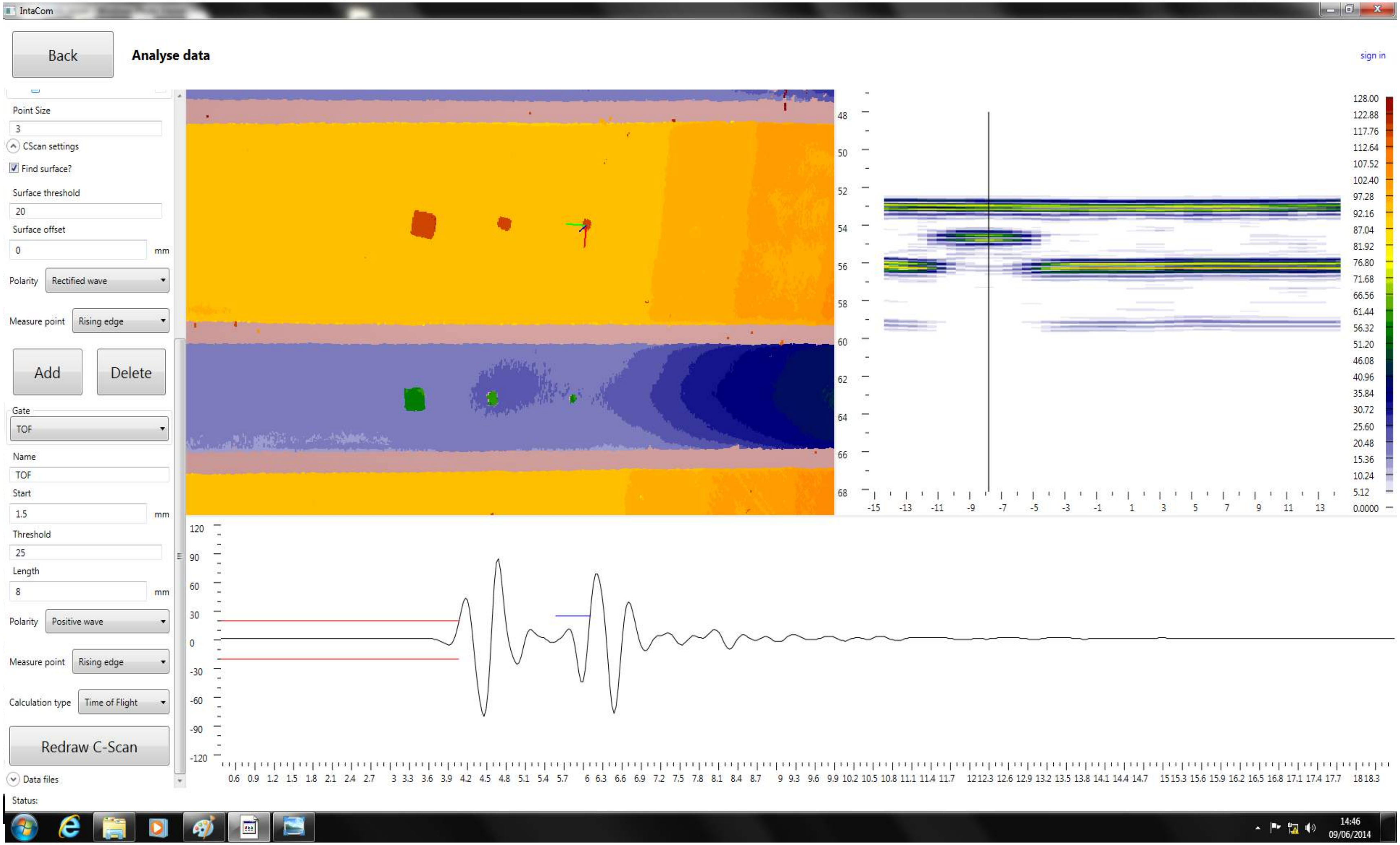


Scanning of large components



- 2.5 x 1m winglet

Scanning of large components



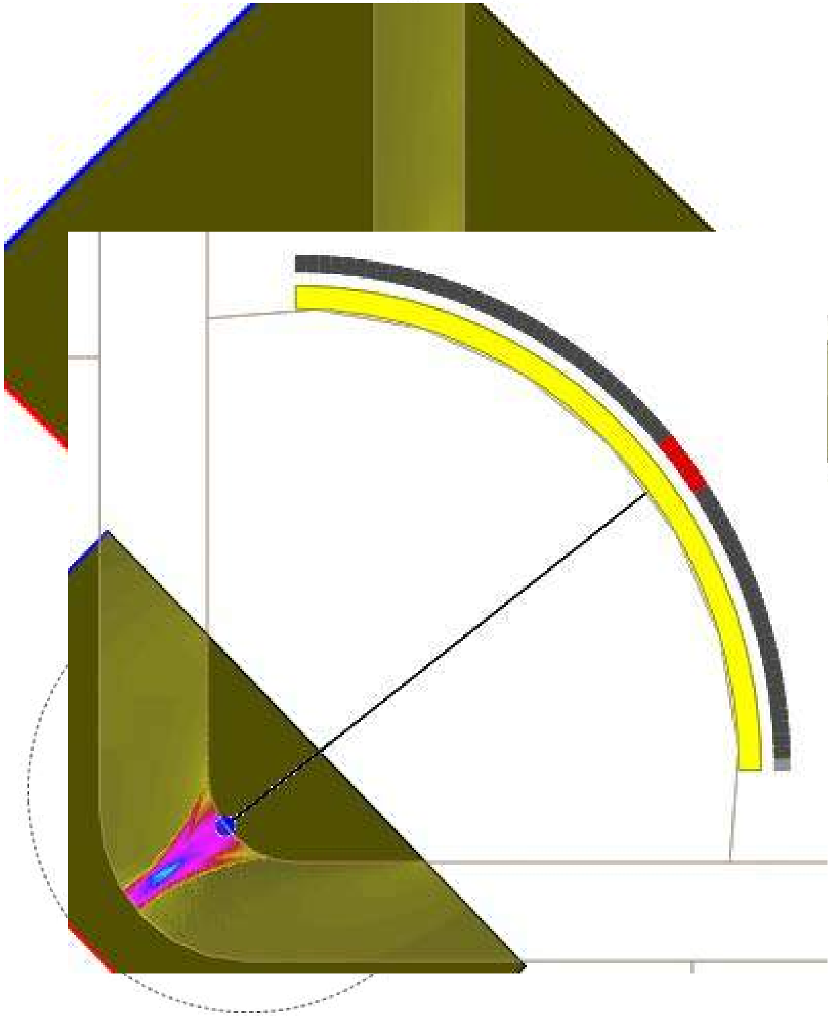
Inspection of radii

128 element Curved array probe focusses through the centre of radius

Can cope with 10 to 15mm external radii

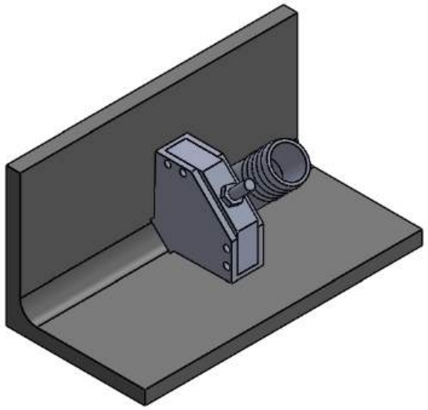
Also works on internal radii

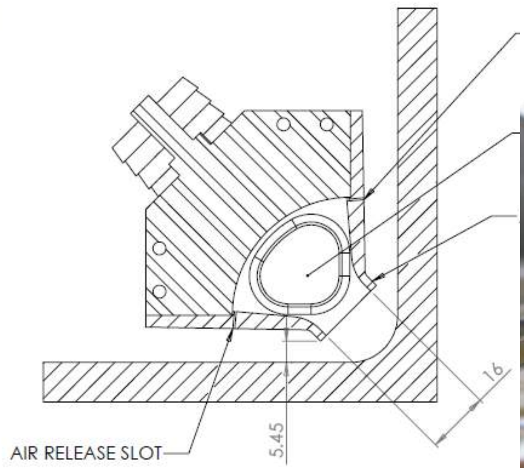
Can cope with 6 to 12mm internal radii

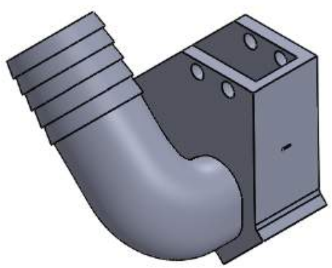


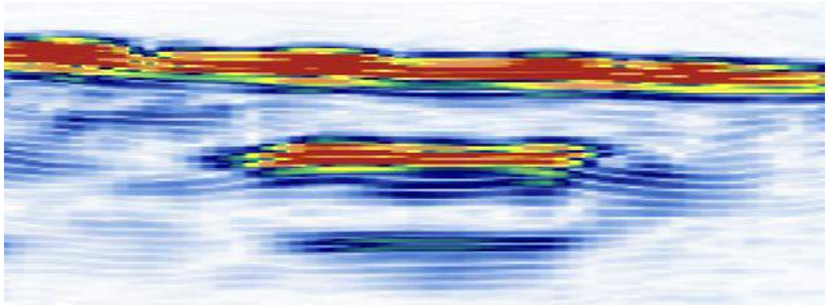
Water nozzle jet design – Iteration 1

NOZZLE FOR INSPECTION OF INNER RADIUS





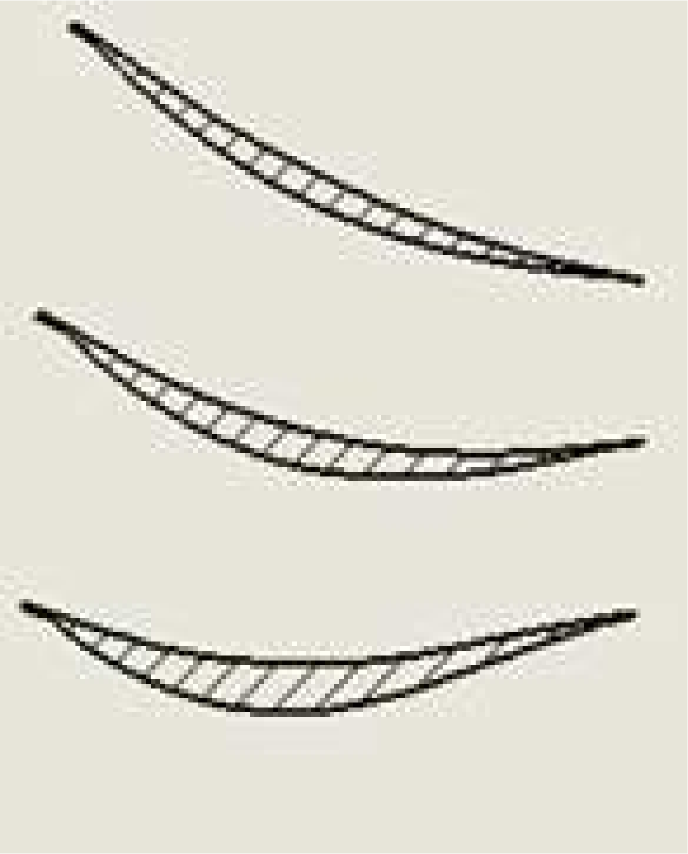




3 x 3mm tape insert

Complex curvature and taper

Aerofoil sections have continuously changing curvature and thickness

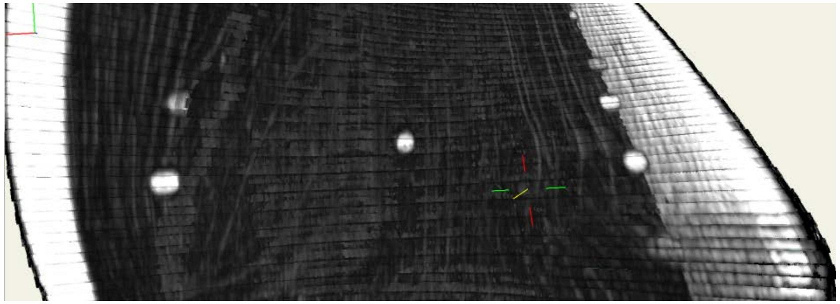


Typical aerofoil cross-sections

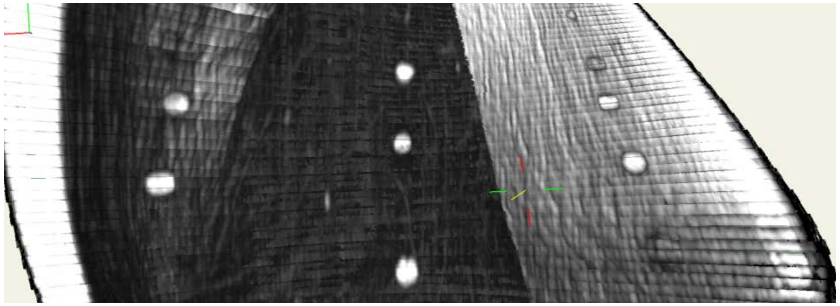
Note large variation in thickness

Traditional gating

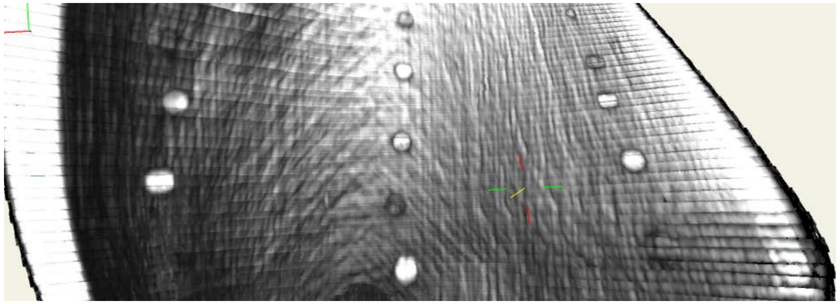
Surface to 5mm: Near surface defects are visible, but so is the backwall response at the edges



Surface to 15mm: Deeper defects are now in the gate, but more of the backwall is in the gate too, making the defects at the edge more difficult to identify



Surface to beyond backwall: Everything is now within the gate, so discriminating between defect responses and back wall responses by amplitude alone is difficult.

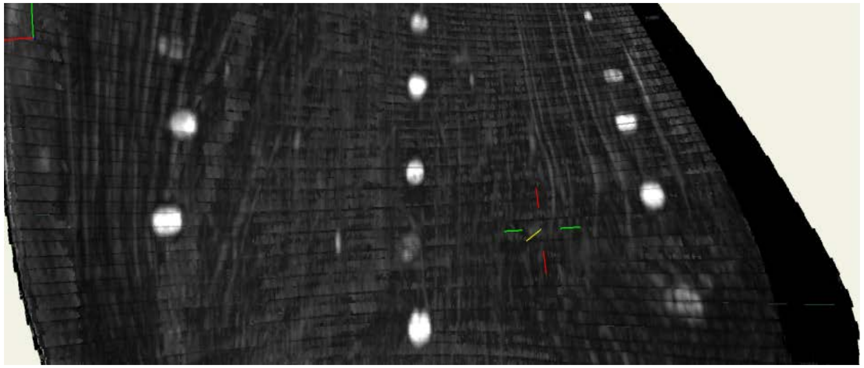


Adaptive gating

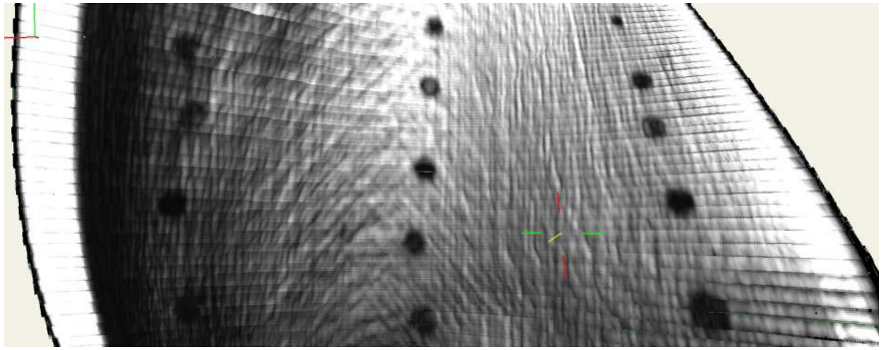
CAD Data guiding robot is used to set gate positions for every A-scan

Front surface to back wall:

All defect responses are present but the back wall reflections are completely cut out, making identification of reflective flaws much easier.

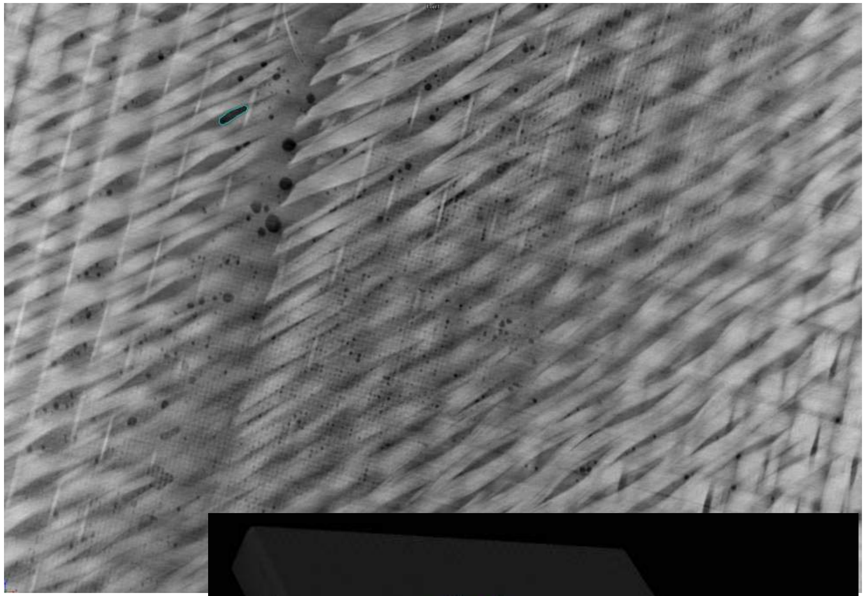


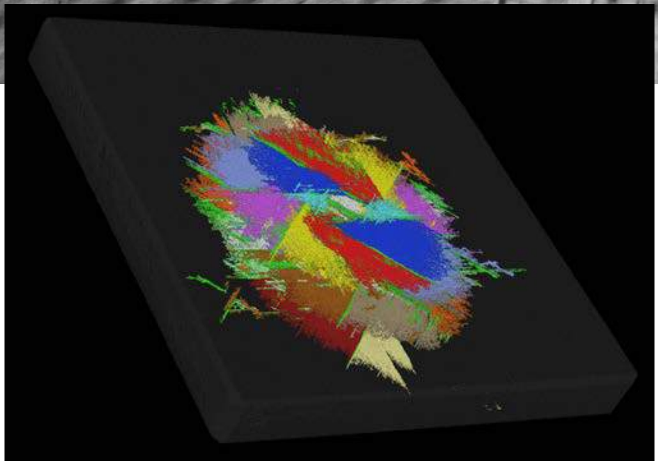
Backwall only: The gate is set to just follow the back wall echo. Flaws are shown as shadows on the back wall signal



High res imaging - Microfocus CT

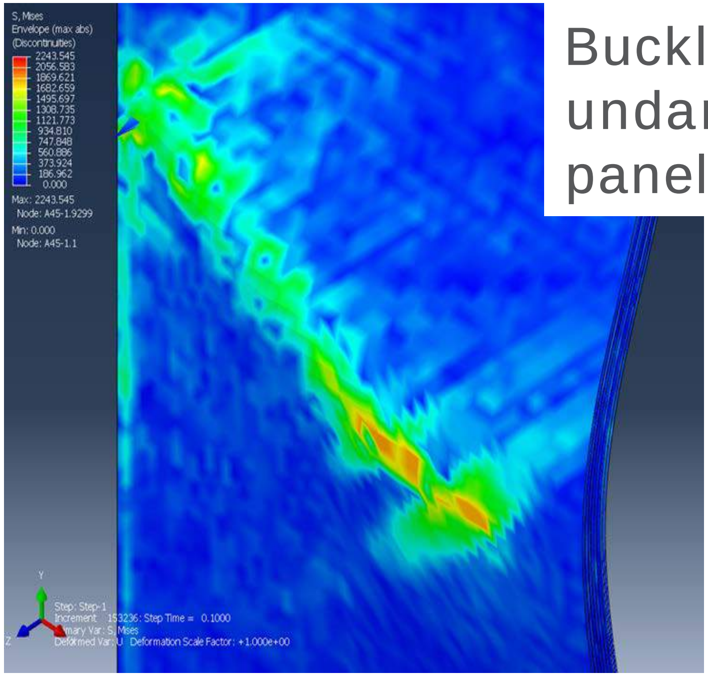
- Microfocus CT radiography can reveal features as small as 15microns
- Note the tiny voids in this composite weave
- This data is combined with high resolution ultrasonic imaging can be used to create an accurate map of damage



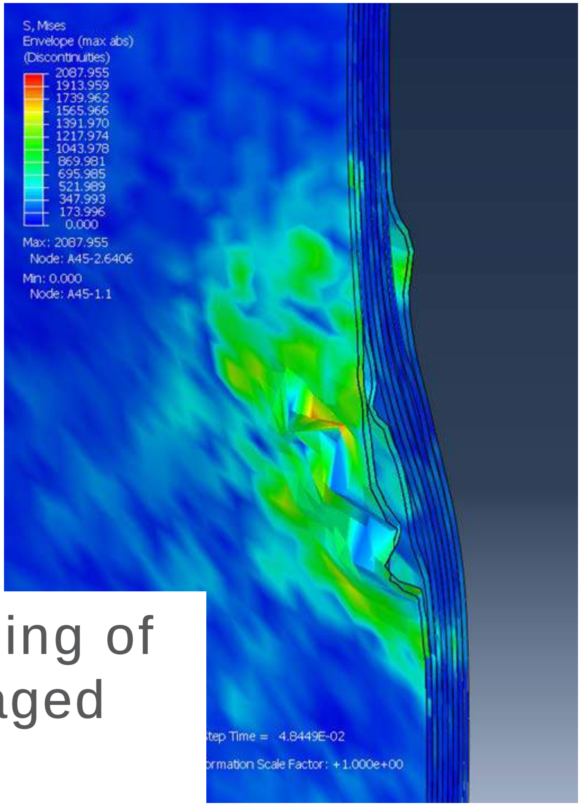


Realistic modelling of damage

- Damaged part is scanned using UT and CT
- Damage in each ply is imported into FEA model
- Compressive loads are applied

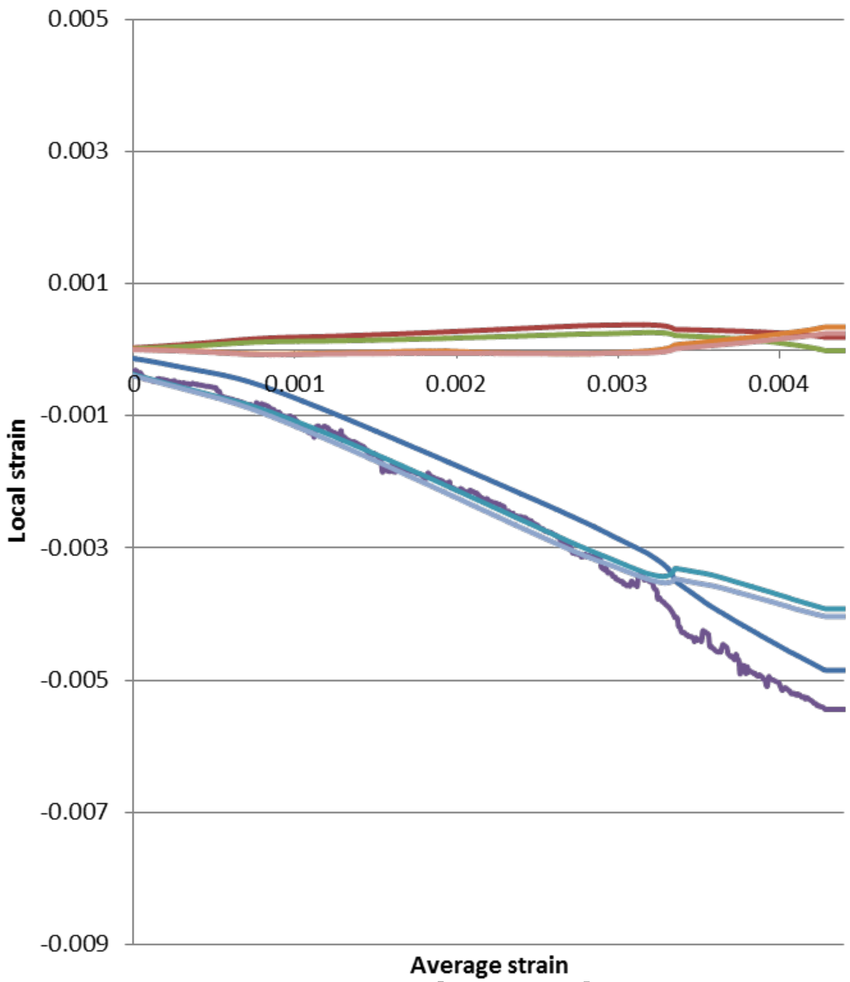


Buckling of undamaged panel

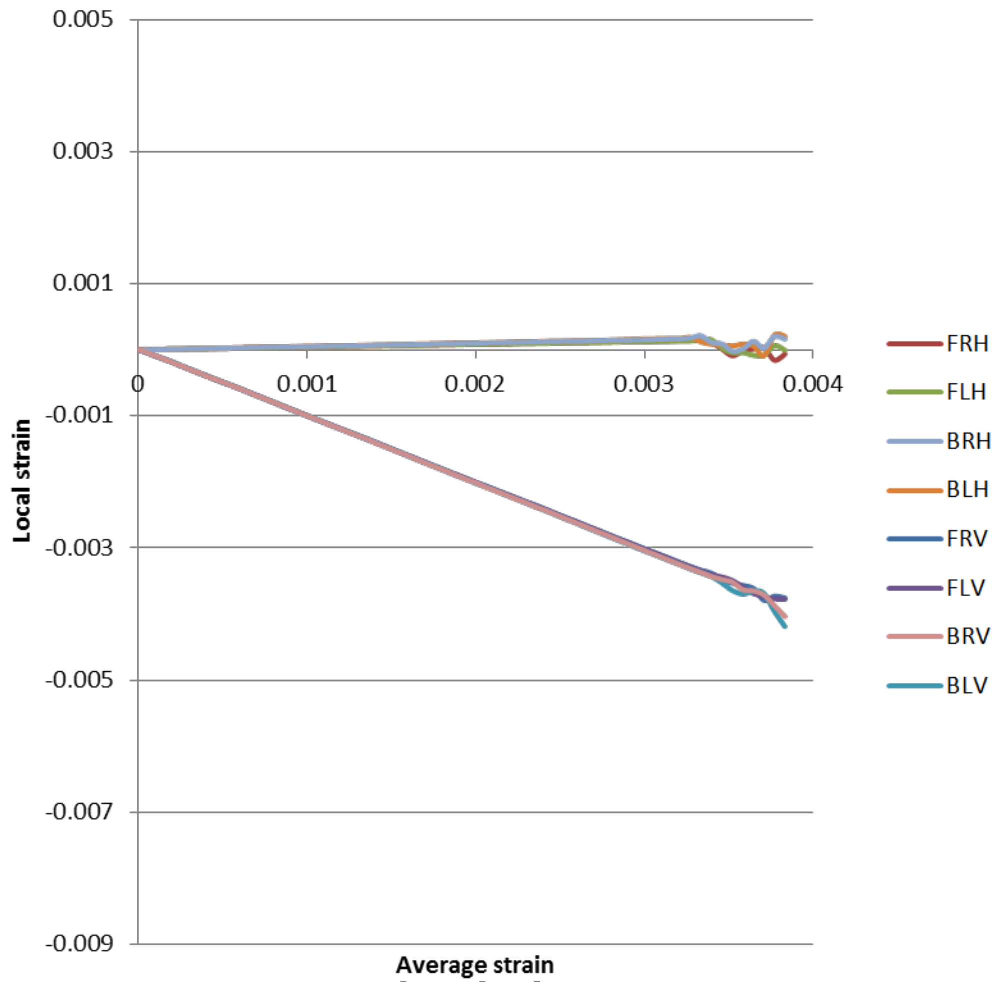


Buckling of damaged panel

Comparison of simulated and actual strain gauge readings



Experimental



Simulation

Questions?

Thank you for listening

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