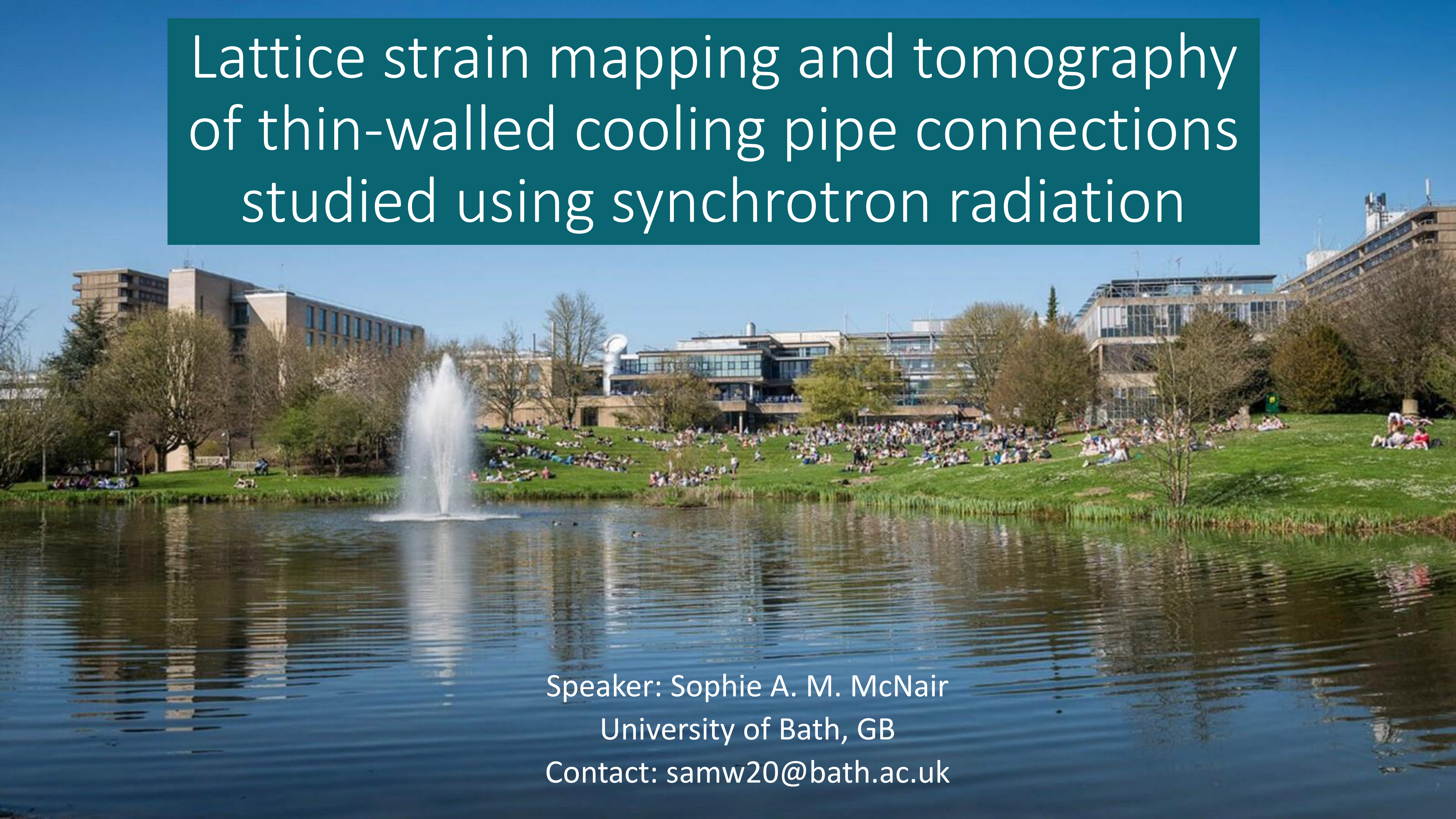
Lattice strain mapping and tomography of thin-walled cooling pipe connections studied using synchrotron radiation



Speaker: Sophie A. M. McNair
University of Bath, GB
Contact: samw20@bath.ac.uk

Introduction

- We have performed in-situ tests on tension loaded thin-walled joints at the UK's synchrotron facility, Diamond Light Source
- We have tested:
  - Two laser welded designs
  - Two soldered designs
  - Orbitally welded designs
- We have utilised x-ray diffraction techniques and tomography to track changes in stress distribution during loading

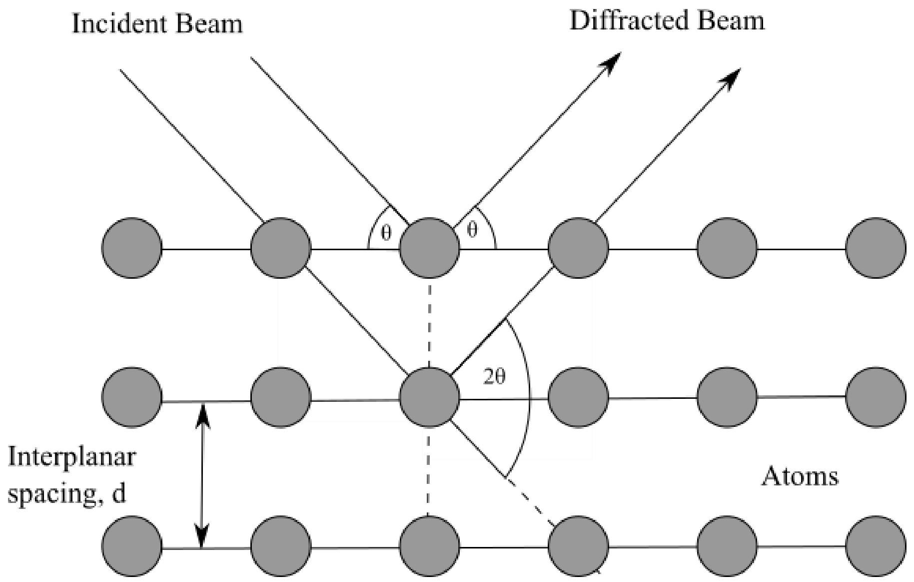
diamond

UNIVERSITY OF BATH

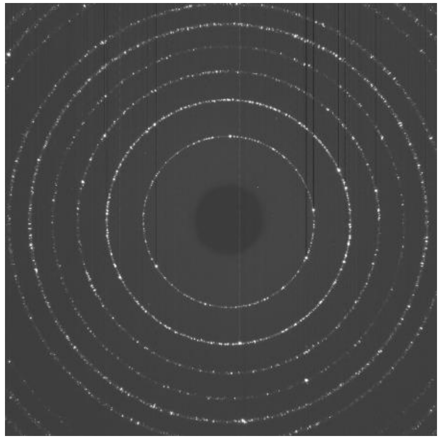
Theory

- X-Ray diffraction (XRD) is a technique used to characterise position of atoms, arrangement in their unit cell and spacing between atomic planes
- Incident x-rays are scattered by the material, and their diffracted beam is directed towards a detector to produce a unique diffraction pattern

Theoretical scattering of an incident x-ray upon a crystalline material

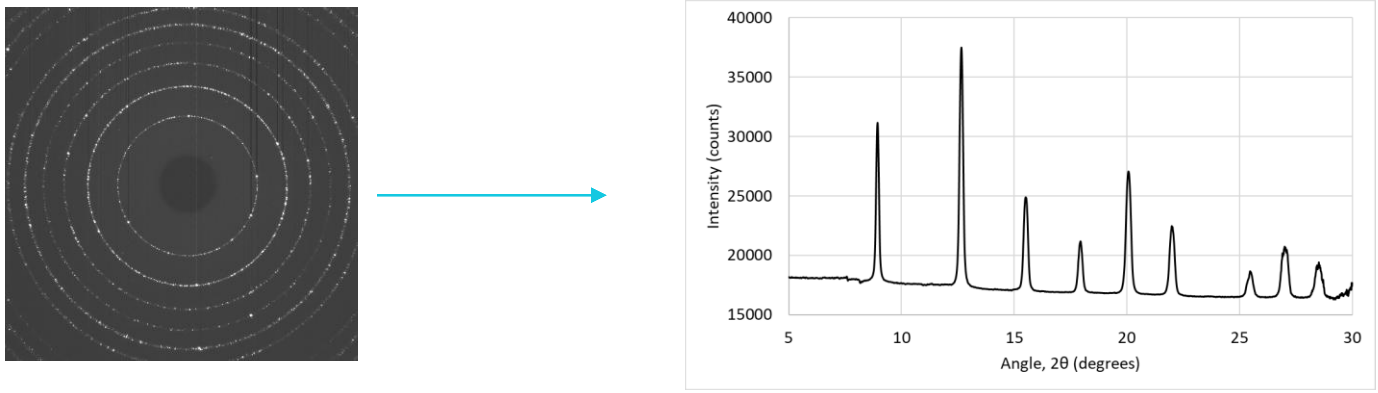


Diffraction pattern output by the detector

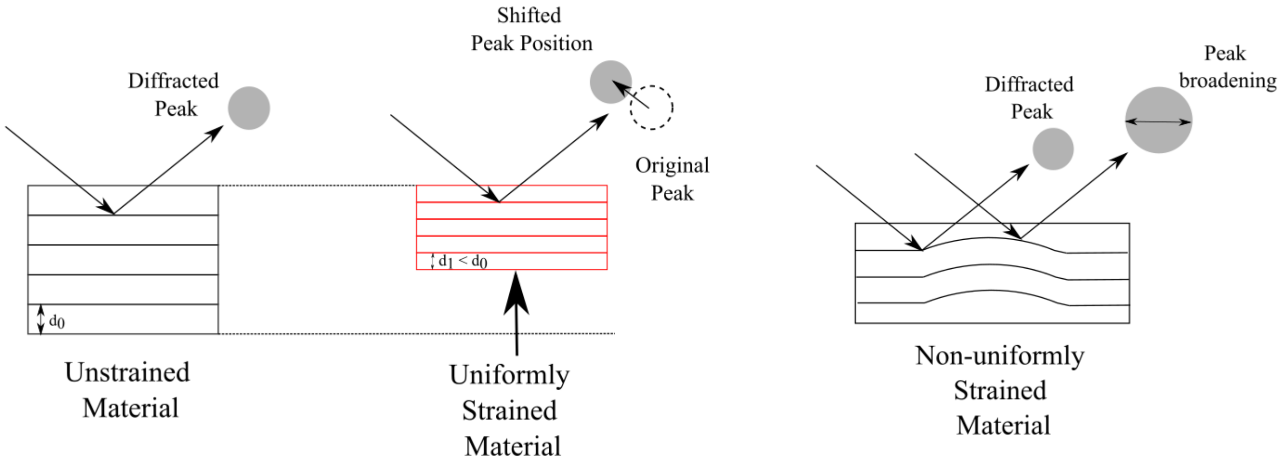


Theory

- Azimuthal integration reduces the 2D images into a 1D diffractogram, intensity against angle
- The peaks can be studied to directly determine the interplanar spacing, d, as well as strains in the material
- A uniformly strained material will have a displaced peak, while a non-uniformly will show peak broadening



Azimuthal Integration to reduce data into 1D



Effect of strain on the 1D diffraction pattern

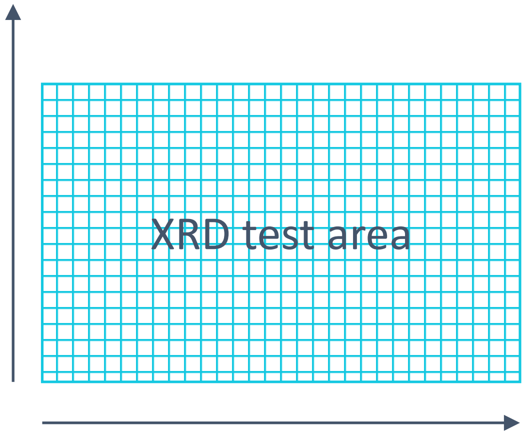
Experiment

- Our experiment studied different types of thin-walled cooling pipe connections, under progressive tensile loading
- Samples were placed in the synchrotron beam in a specially designed load cell which did not interrupt the beam, and tested in-situ
- High resolution tomography was carried out, as well as XRD patterns
- For the XRD patterns, samples were scanned over a known area, with a constant step size
- This produced a diffraction pattern per point, with 100s of patterns produced per sample

Sample

Tension Loading

3.6mm across, 1 XRD pattern taken at 0.2mm intervals = 19 patterns

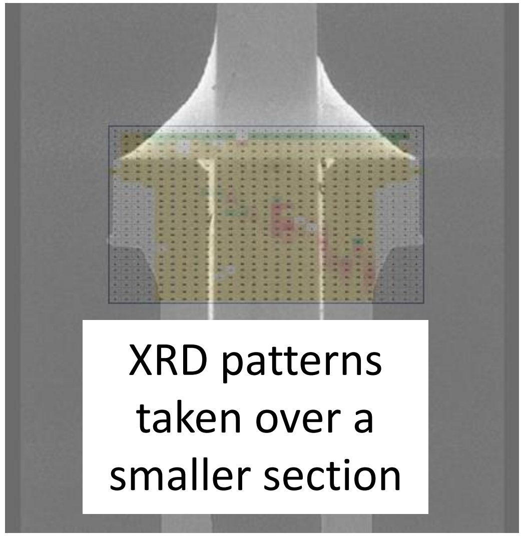


5mm across, 1 XRD pattern taken at 0.2mm intervals = 26 patterns

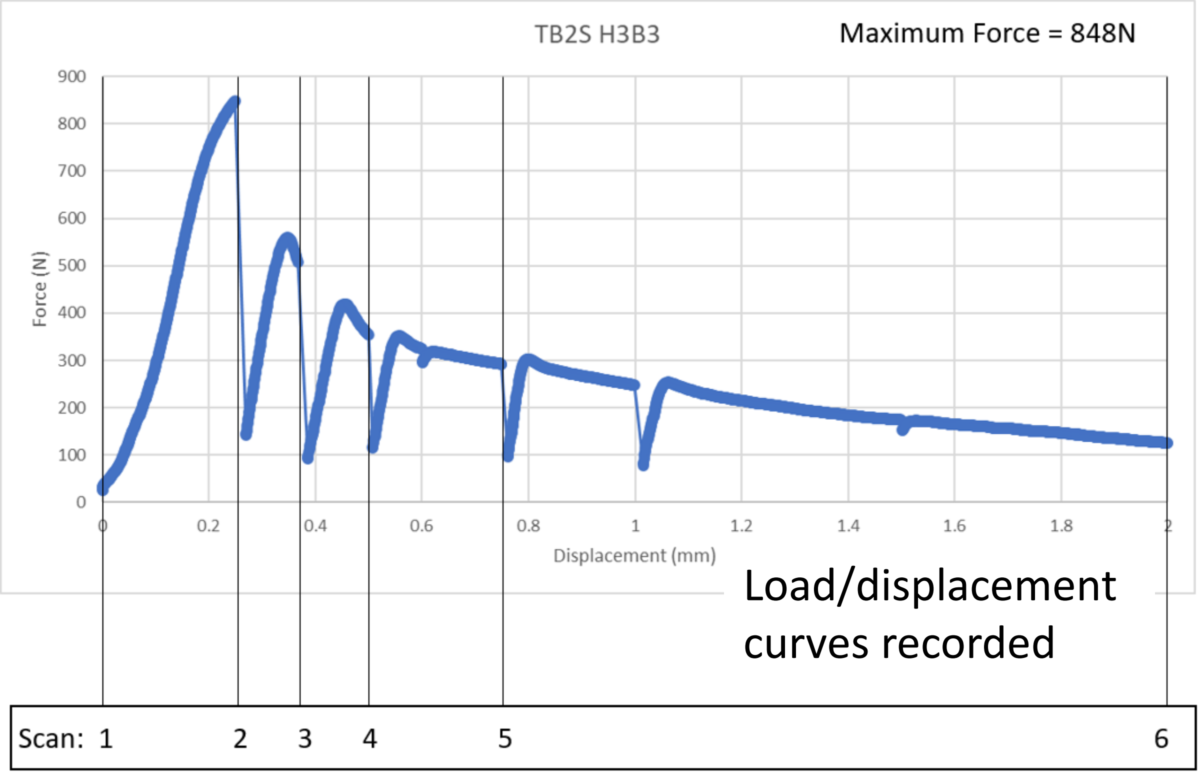
19 * 26 = 494 unique diffraction patterns for a 5mm * 3.6mm test area

Experiment

Sample under tensile load

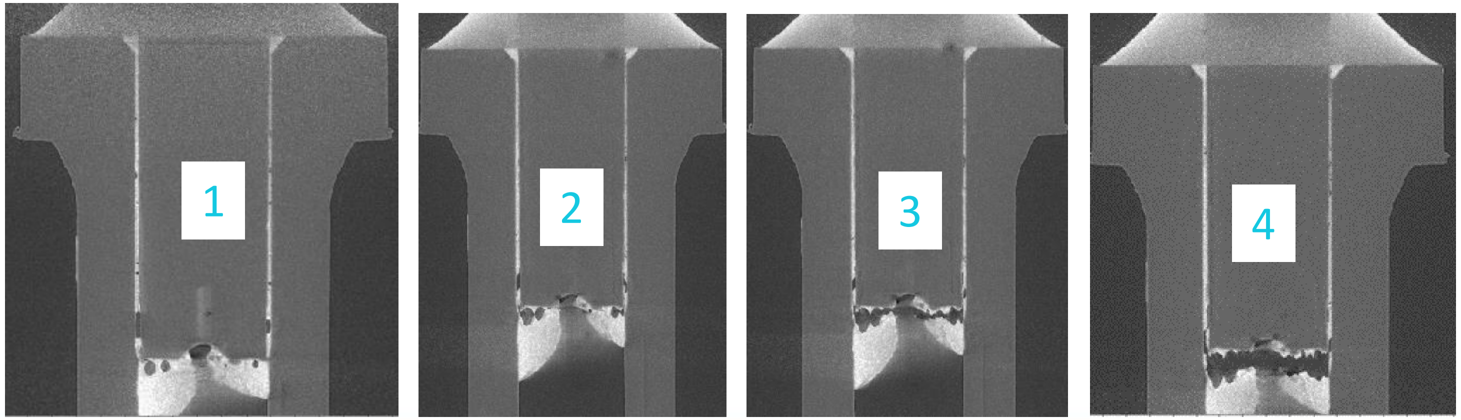


XRD patterns taken over a smaller section



Load/displacement curves recorded

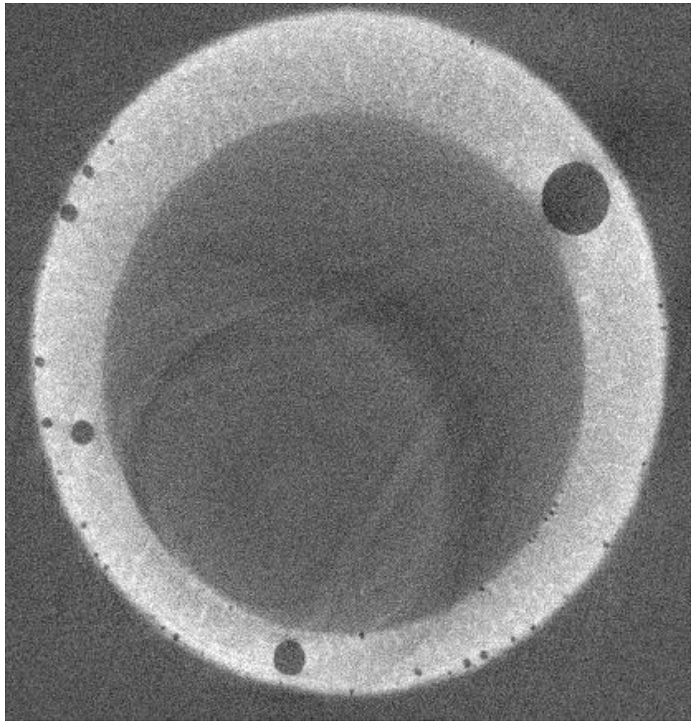
Tomography scans at each load increment in situ

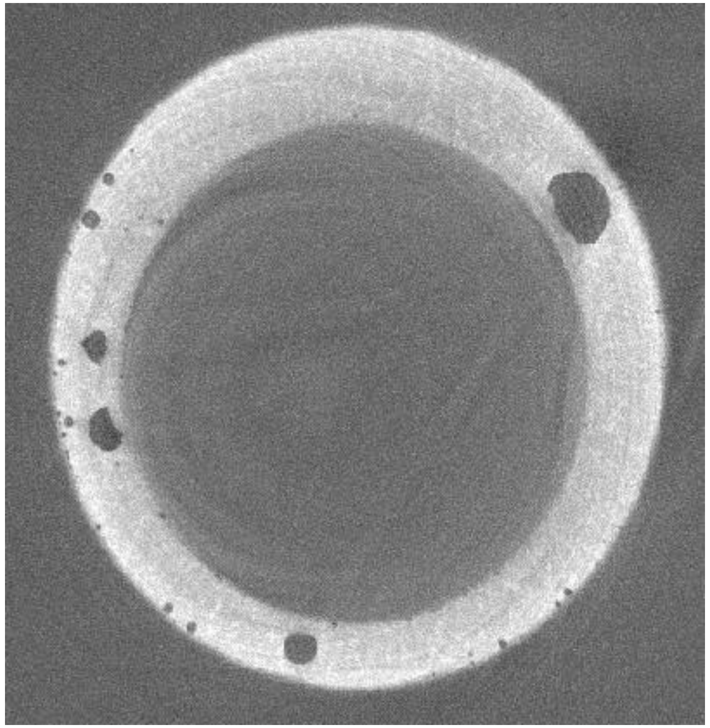


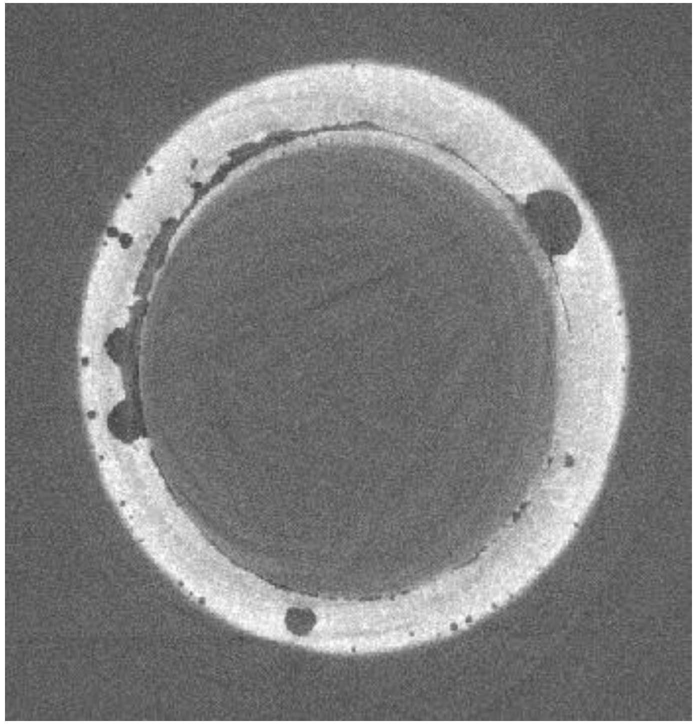
Tomography

Progressive load

TB2S







Unloaded – Voids present but round and distinct

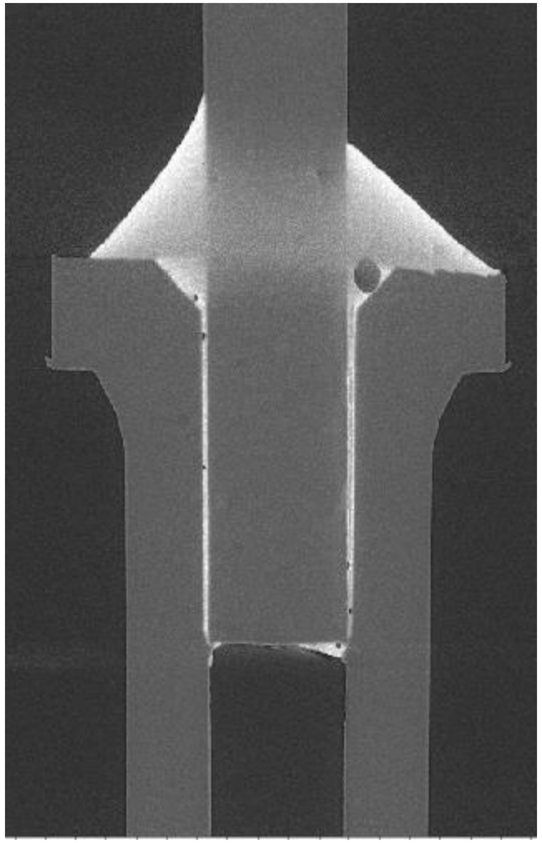
0.5mm displacement – voids beginning to change in shape with some widening seen

0.75mm displacement – crack propagation seen between voids

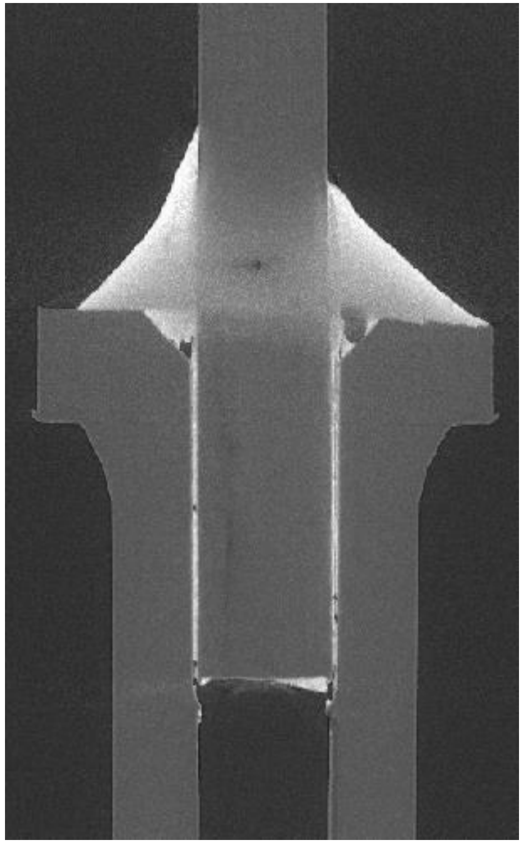
Tomography

Progressive load

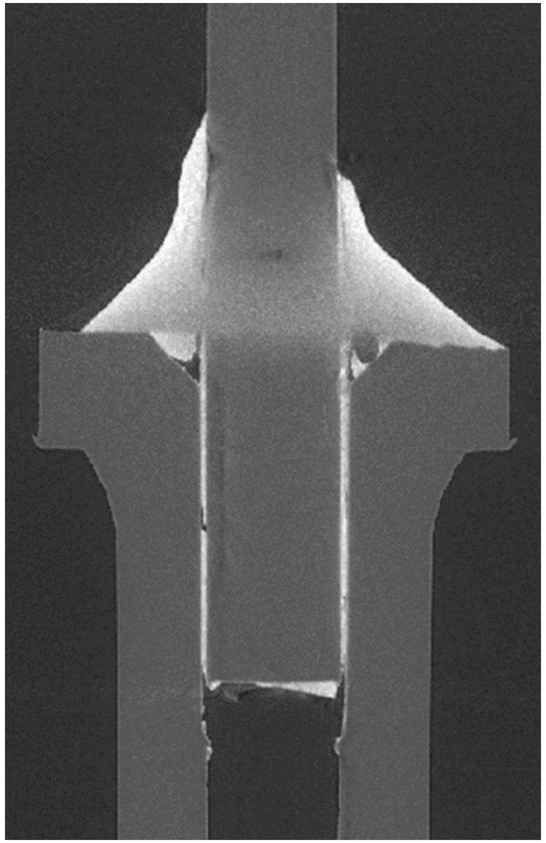
TB2S



Unloaded – Voids present but round and distinct



0.5mm displacement – Cracks forming at edges of voids

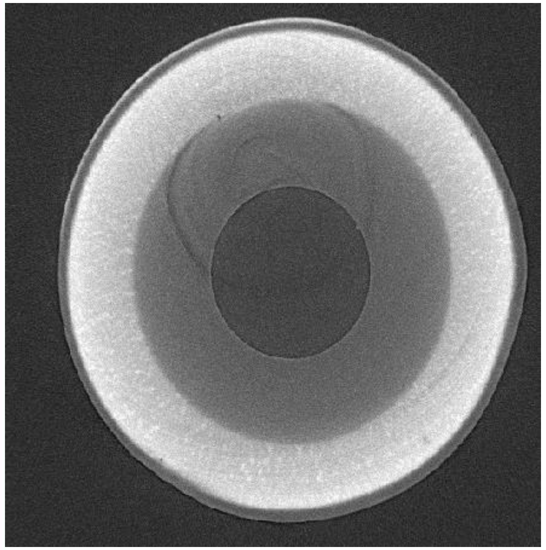


0.75mm displacement – crack propagation along edge of solder, with change in shape at top

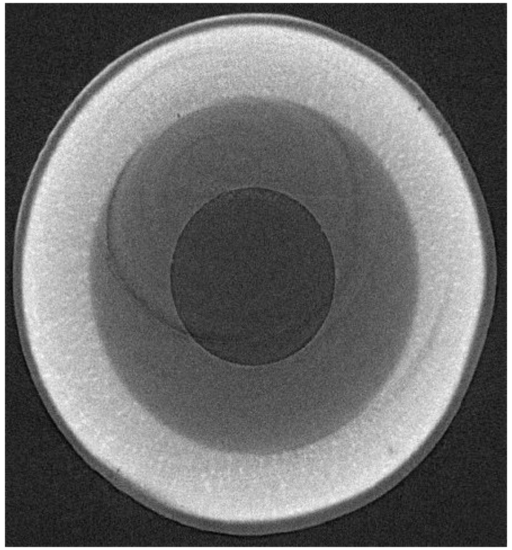
Tomography

Progressive load

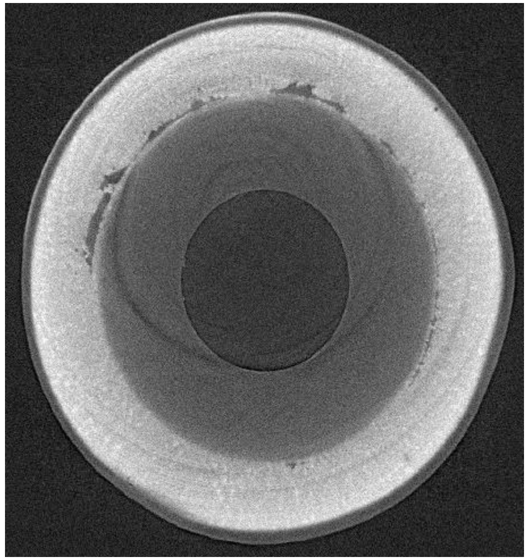
TBPS



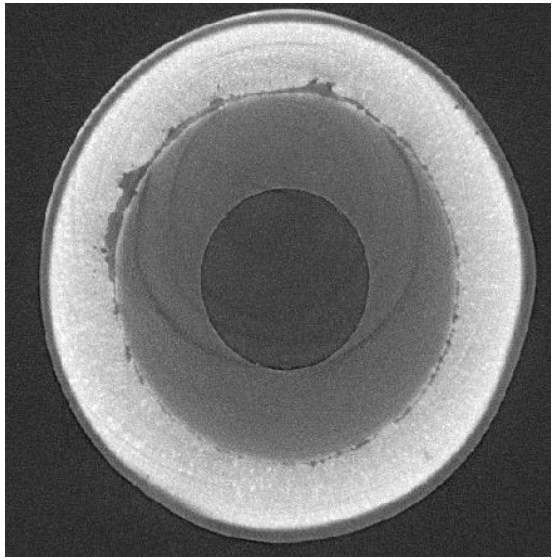
Unloaded



0.25mm displacement



0.50mm displacement

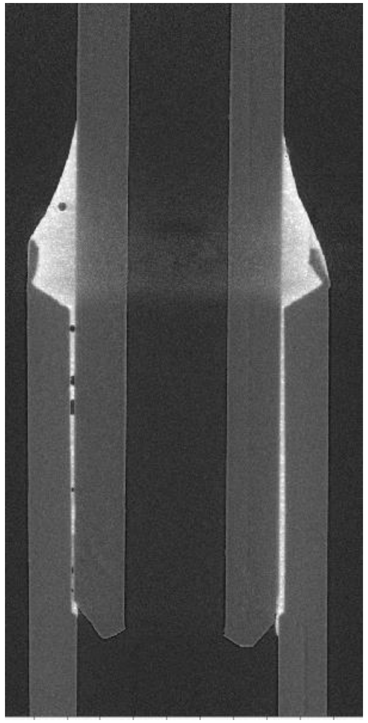


1mm displacement

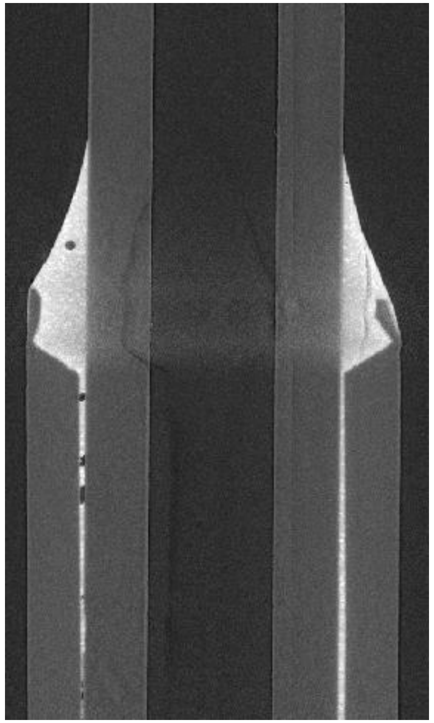
Tomography

Progressive load

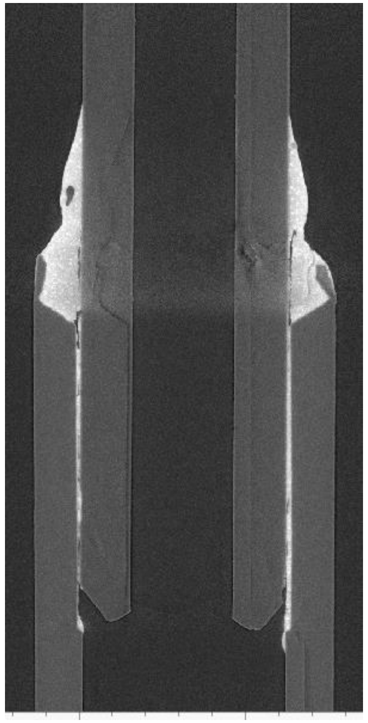
TBPS



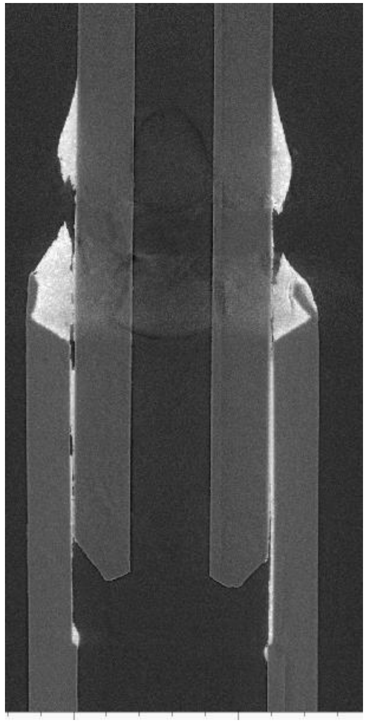
Unloaded



0.25mm displacement



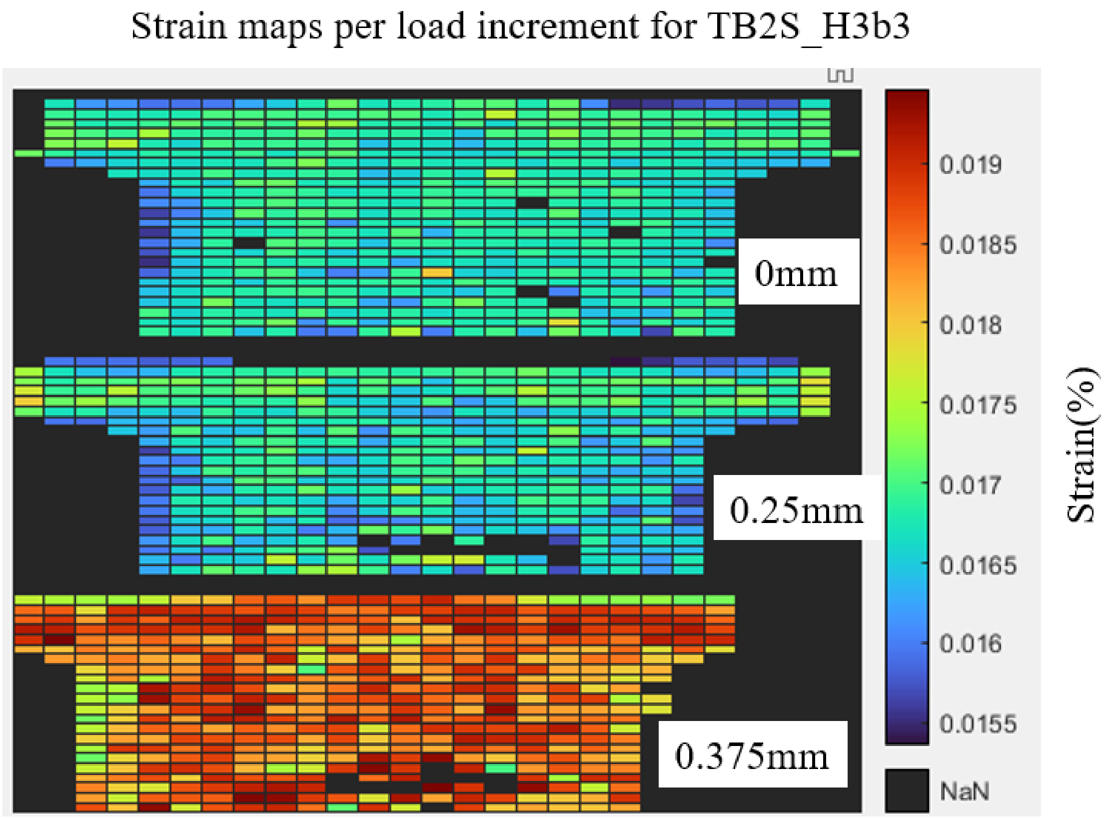
0.50mm displacement



1mm displacement

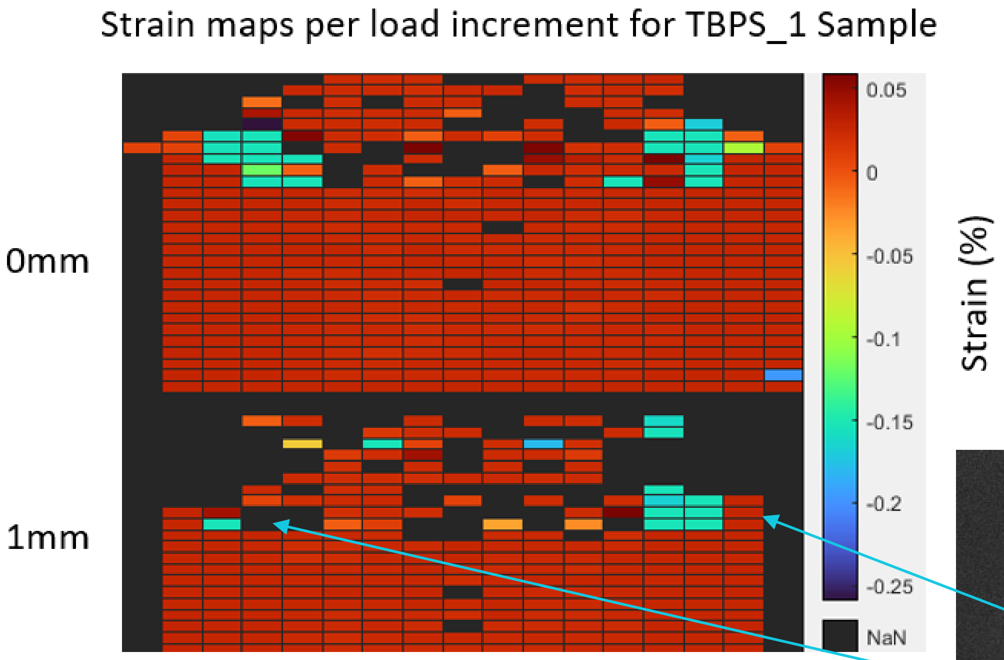
TB2S

- The TB2S samples had relatively even distribution of strain, with low strain at unloaded at 0.25mm displacement and a large increase in strain at 0.375mm
- This shows that although strain is increasing throughout the sample, it is fairly even, with no areas of significantly high strain

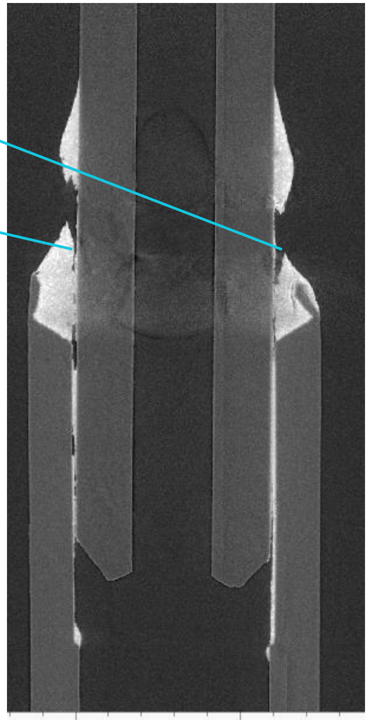


TBPS

- The strain maps show that the areas of high strain are where the failures occur
- However, there is already high strain in these areas before any loading takes place, suggesting that the joining method itself is the source of these high strain areas

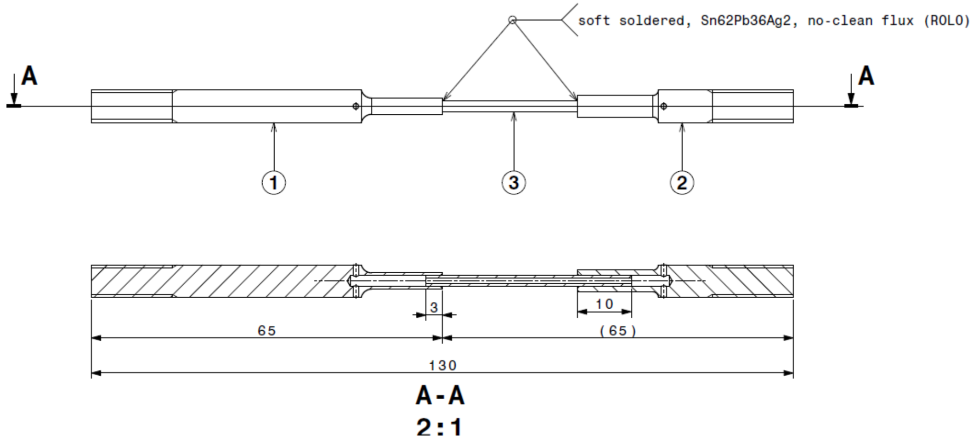


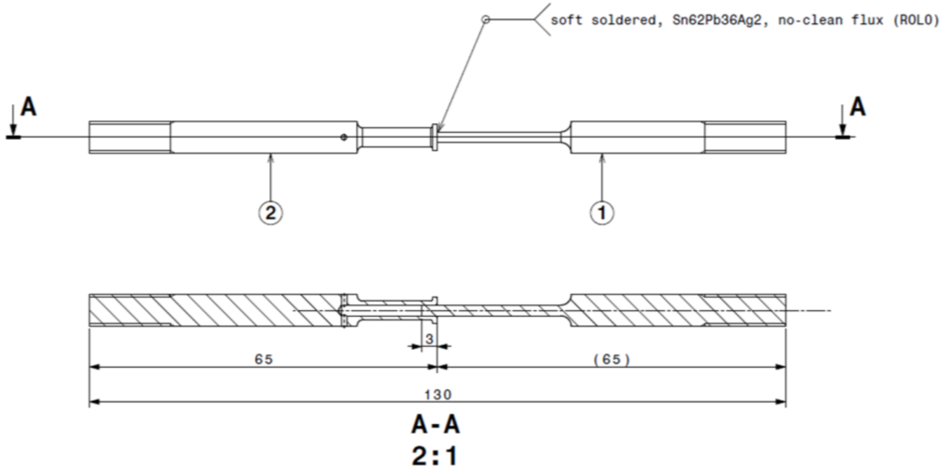
High strain areas at failure points



Soldered Samples Comparison

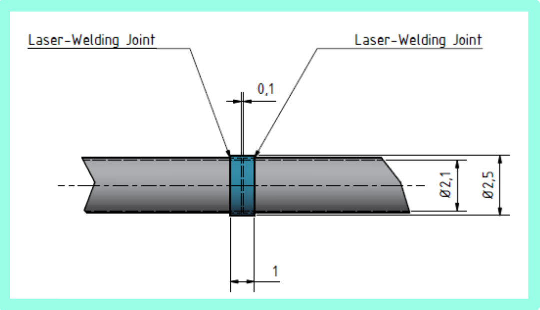
TBPS	TB2S
• Strains localised where heat is applied • Less Voids seen in samples	• Strains more evenly distributed across sample • Vertical strains always higher in magnitude than horizontal • Greater number of voids

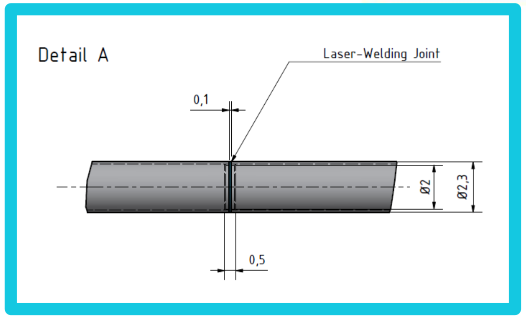


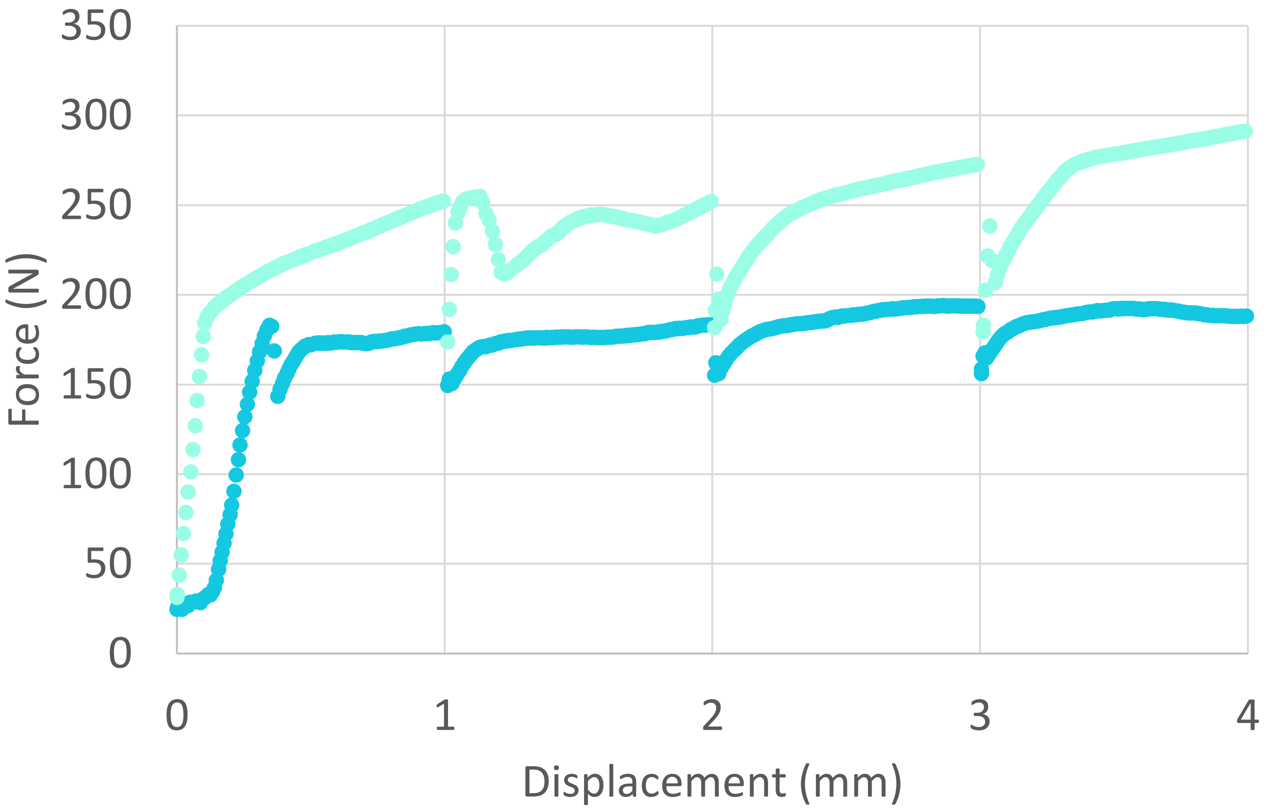


Laser Welded Samples

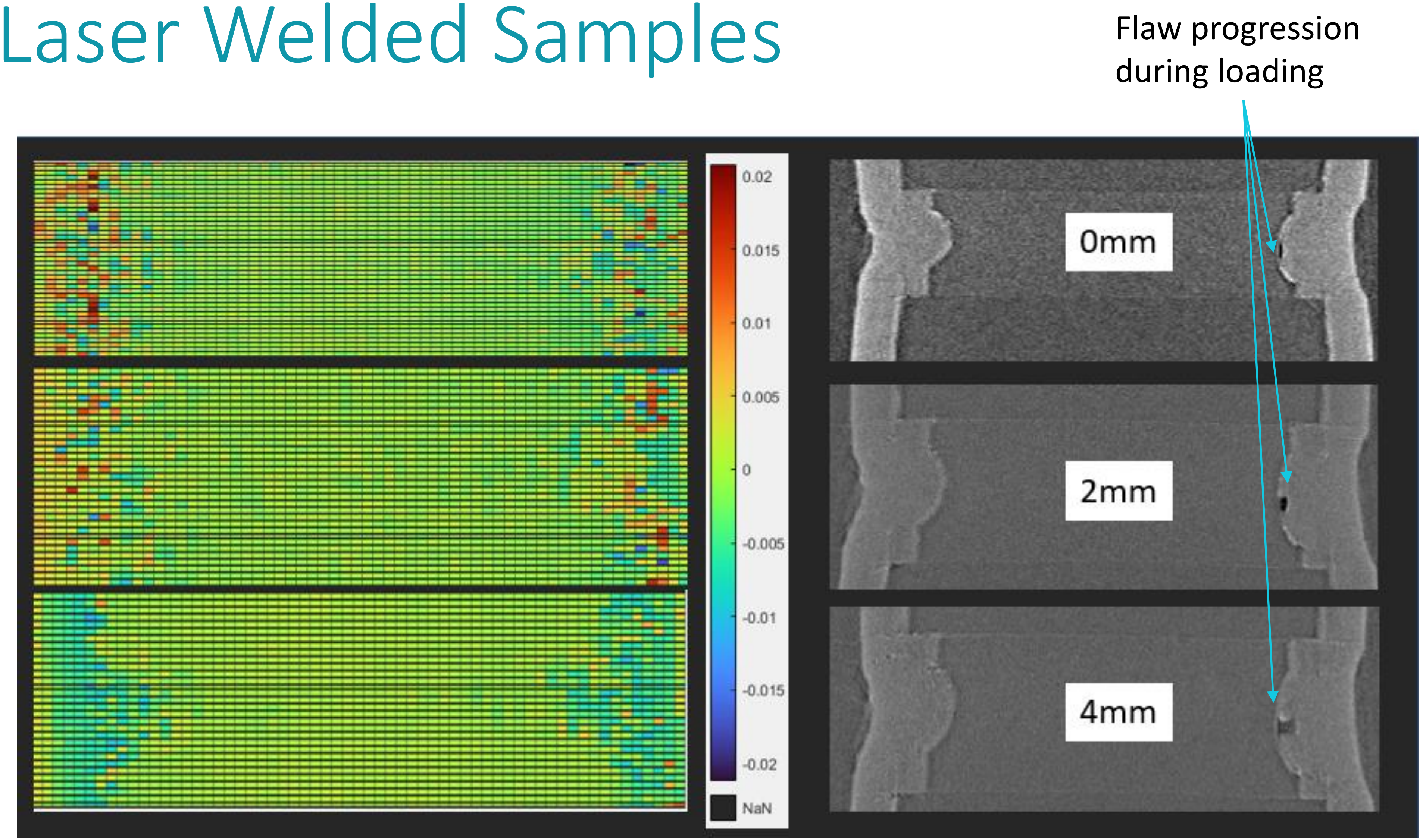
- Two different samples tested – only difference is the insert used to join the two samples
- However, had very different performance from load/displacement curves and from the strain maps





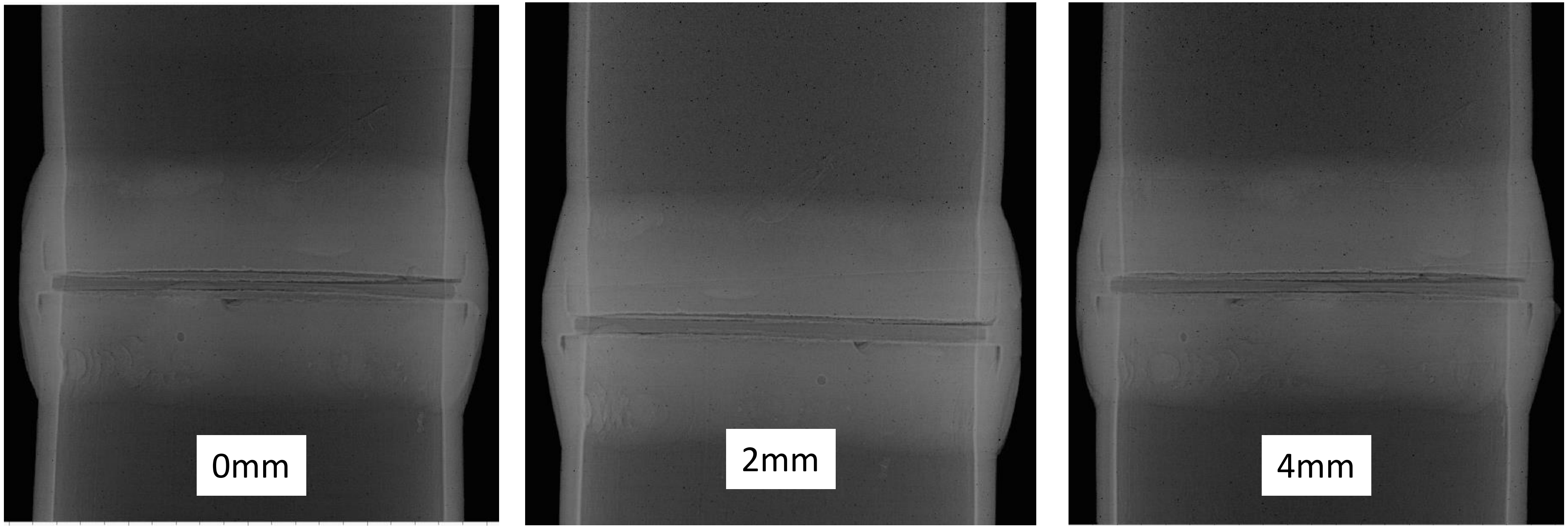


Laser Welded Samples



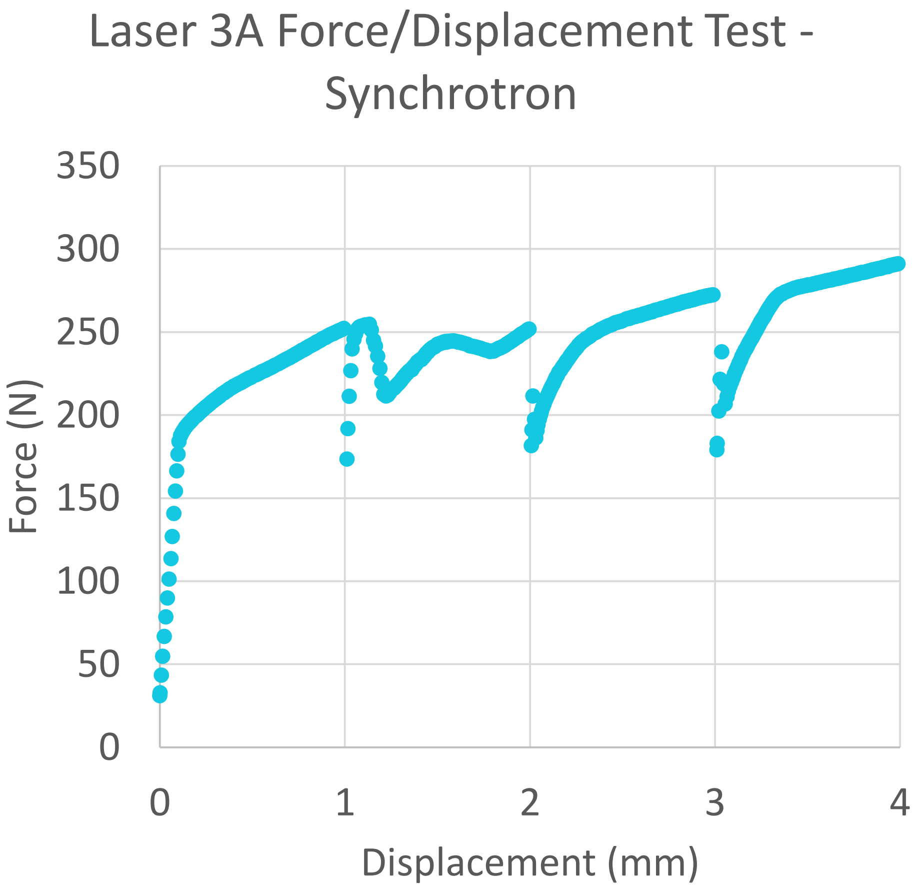
- Here we can see high residual strains around the joint area and from the tomography it can be seen that there is a flaw in the joint
- However, during loading the stresses even out and become less localised

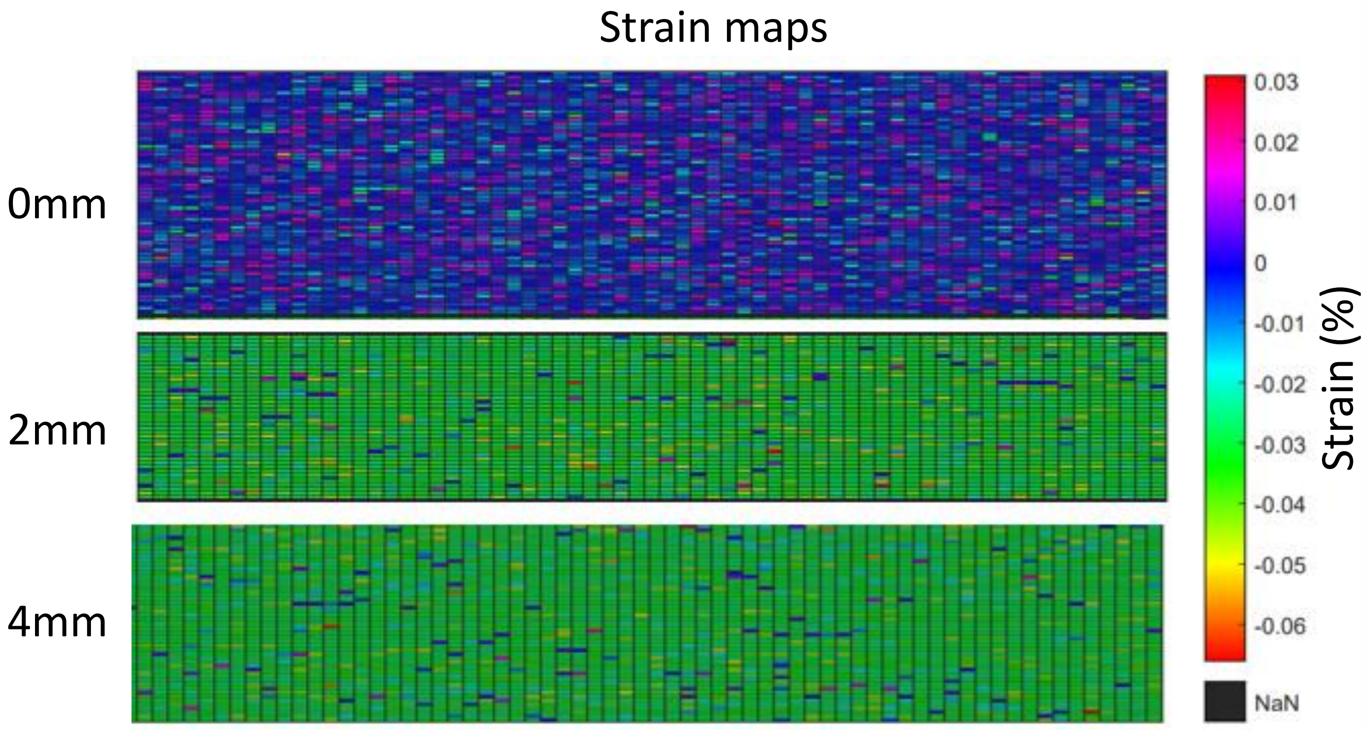
Laser Welded Samples



- For this sample, there was little changes which could be tracked from the tomography, apart from a slight change in shape

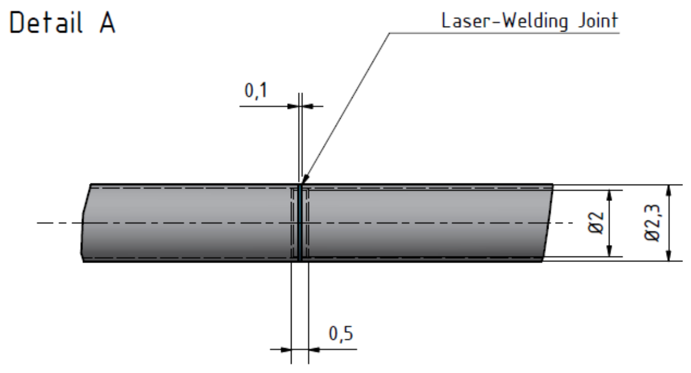
Laser Welded Samples

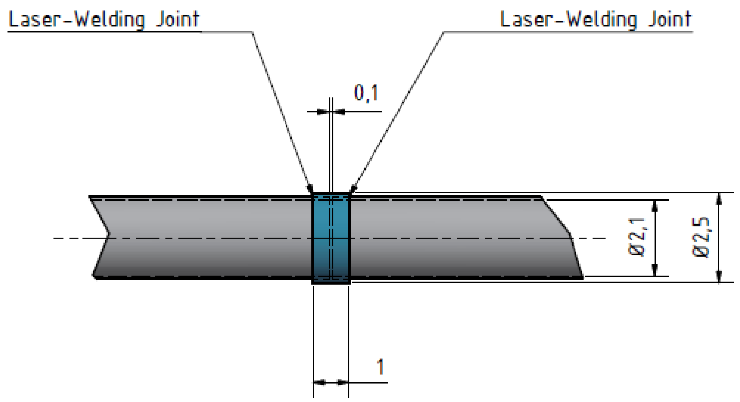




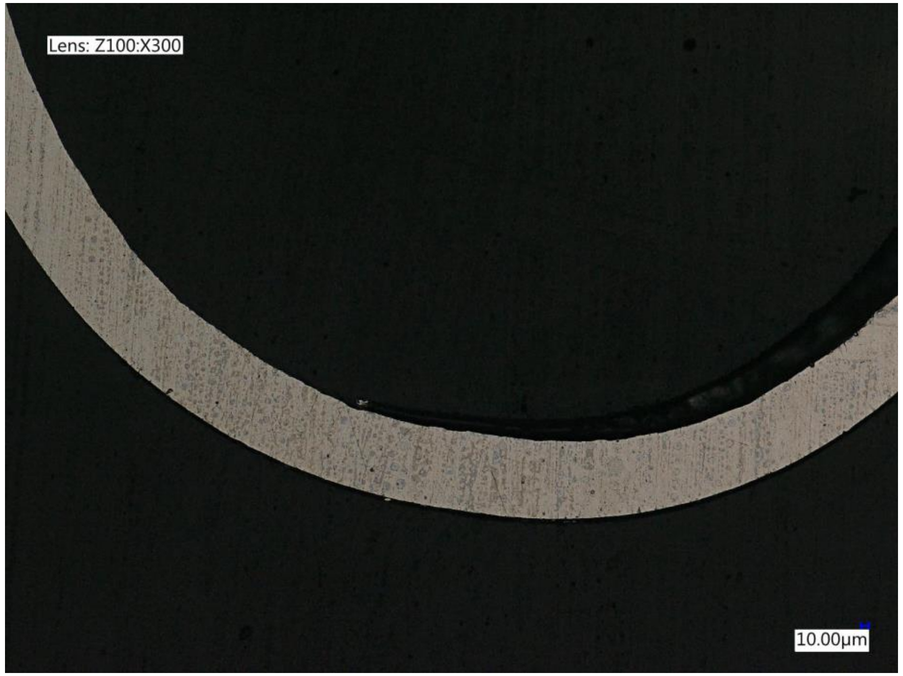
Laser Samples Comparison

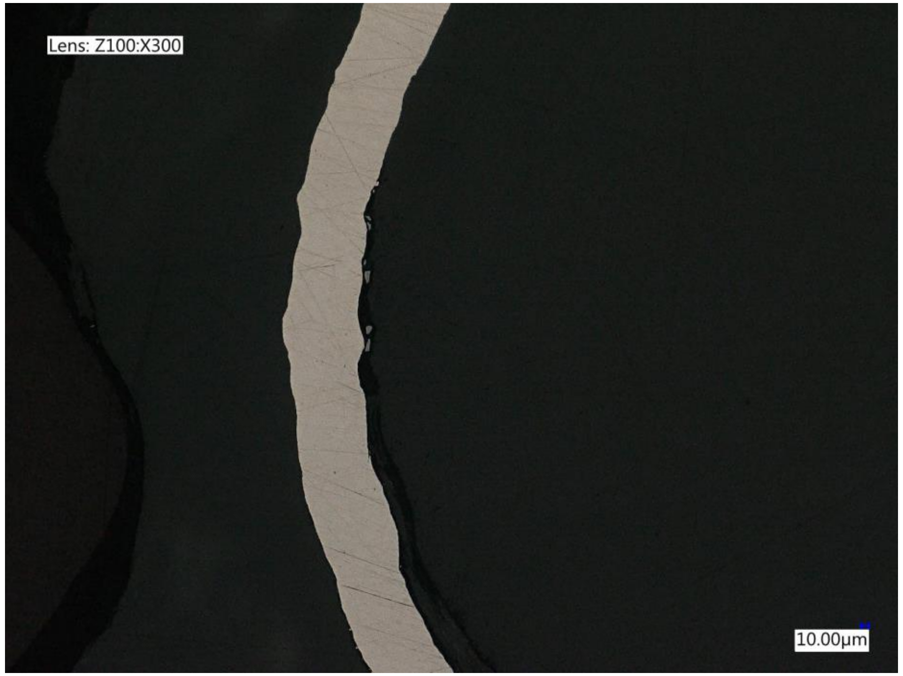
Inner insert	Outer Insert
• Residual stresses focused on each side of joint	• Residual stresses evenly distributed





Optical Microscopy Images

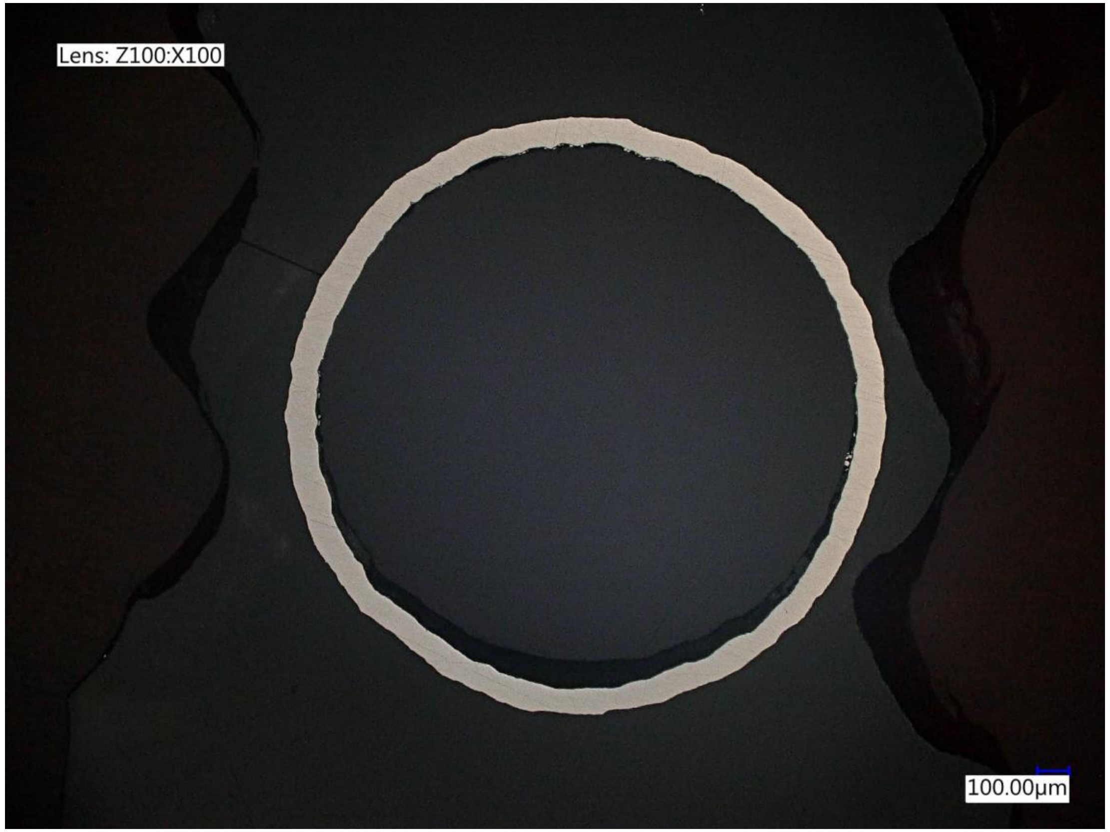




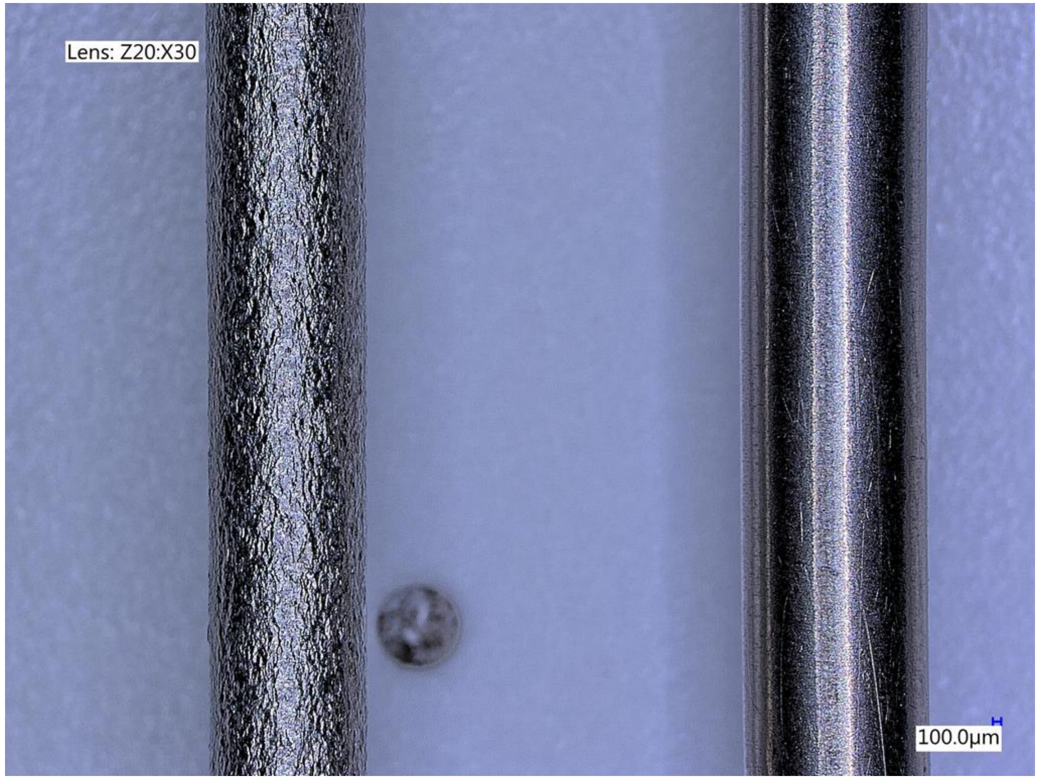
Change in cross section before and after tension loading

Optical Microscopy Images

- Can see clear misshapen features
- Surface texture changes as well as changes in width/dimensions

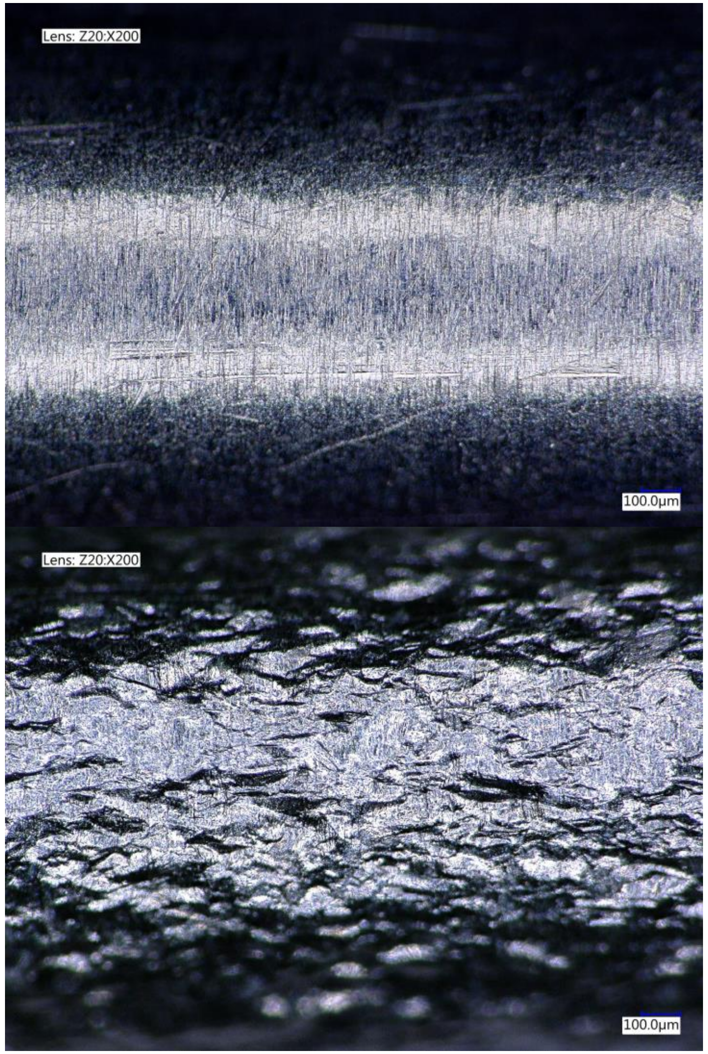


Optical Microscopy Images



Before

After



Changes in surface texture after tensile loading

Conclusions

- Changes in designs of the same type of joining can dramatically change the residual stresses of the unloaded sample, and how stresses are carried during loading
- While tomographic images showed crack propagation through voids, there wasn't much evidence of stress concentration in these areas from the XRD
- Stress concentrations are more likely around areas where residual stress is high from the joining process, such as the heat input on the TBPS samples
- Even without complete joint failure, significant changes in surface texture often occurs

Thank you!

Speaker: Sophie A. M. McNair

University of Bath, GB

Contact: samw20@bath.ac.uk