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Engineering Weld Residual Stresses: from Test-piece to Full Scale Component

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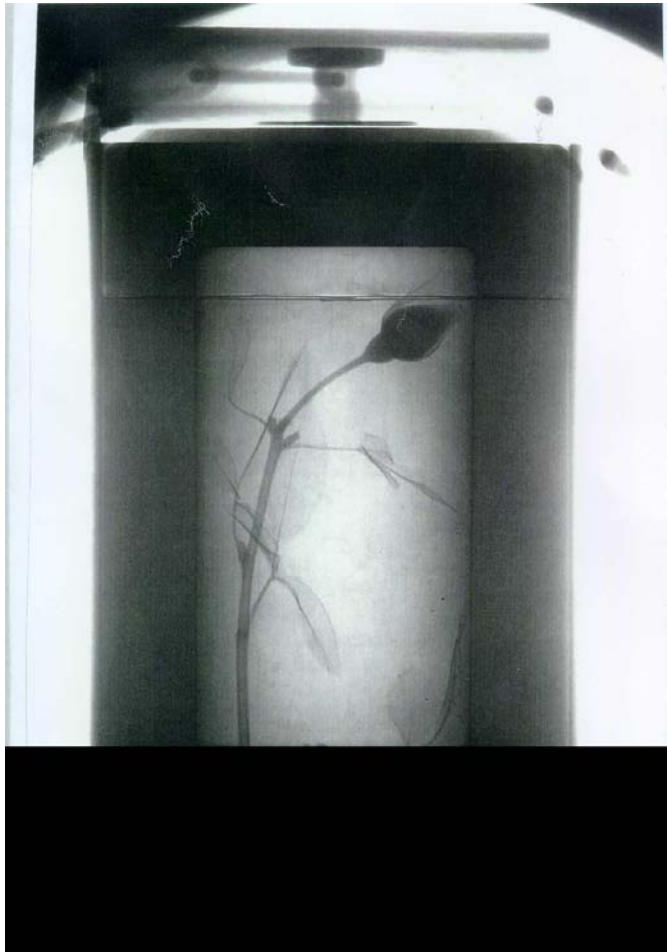
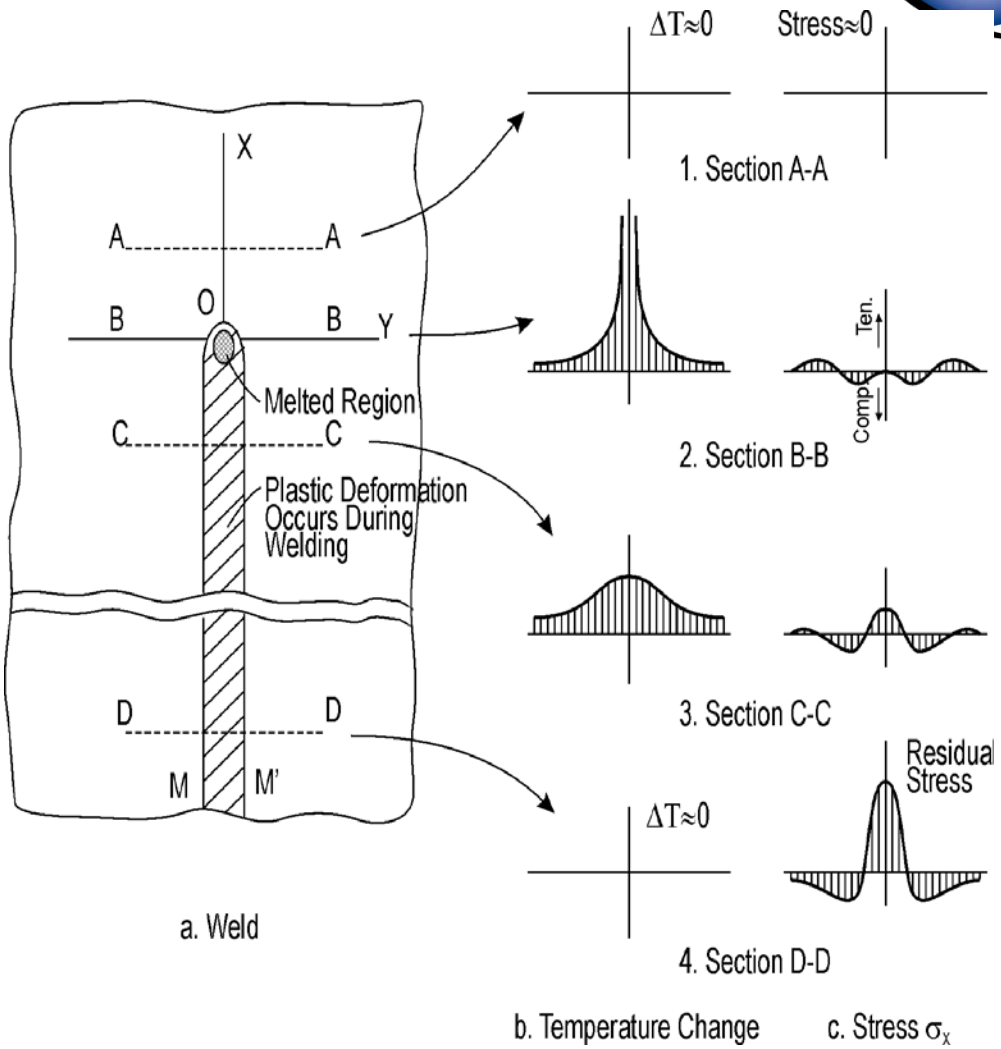


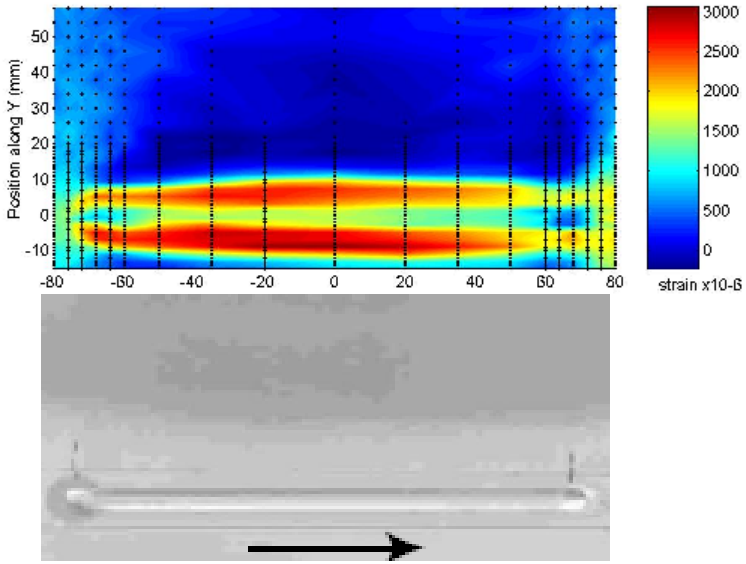
Thanks to: Chalk River, ILL, ESRF, ISIS, Munich Facilities

Weld residual stresses

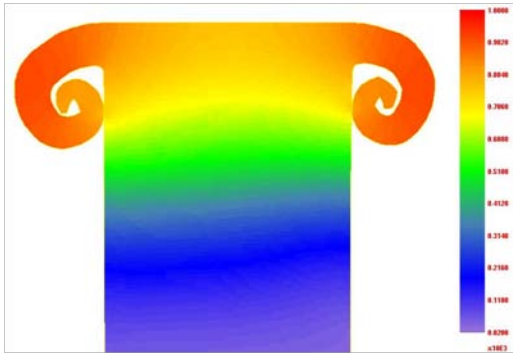
- Welds continue to be a major problem for structural integrity
- Misfits caused by weld metal as it cools
- introduces significant longitudinal weld residual stresses
- Introduces distortion



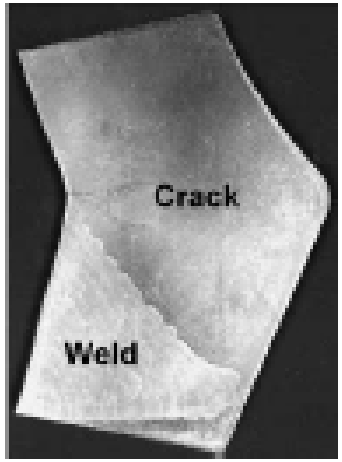
Weld residual stresses

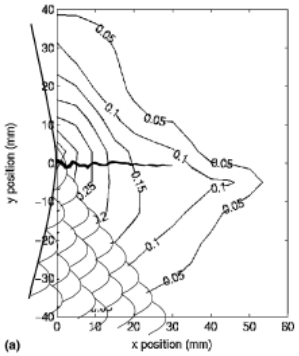


TIG welds

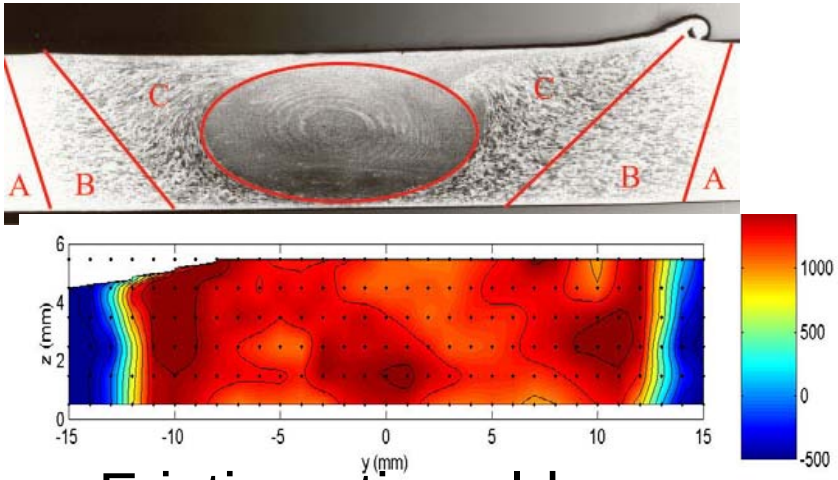


Inertia (rotational) friction welds





Manual metal arc



Friction stir welds

Exemplar 1: Creep cavitation driven by weld residual stresses

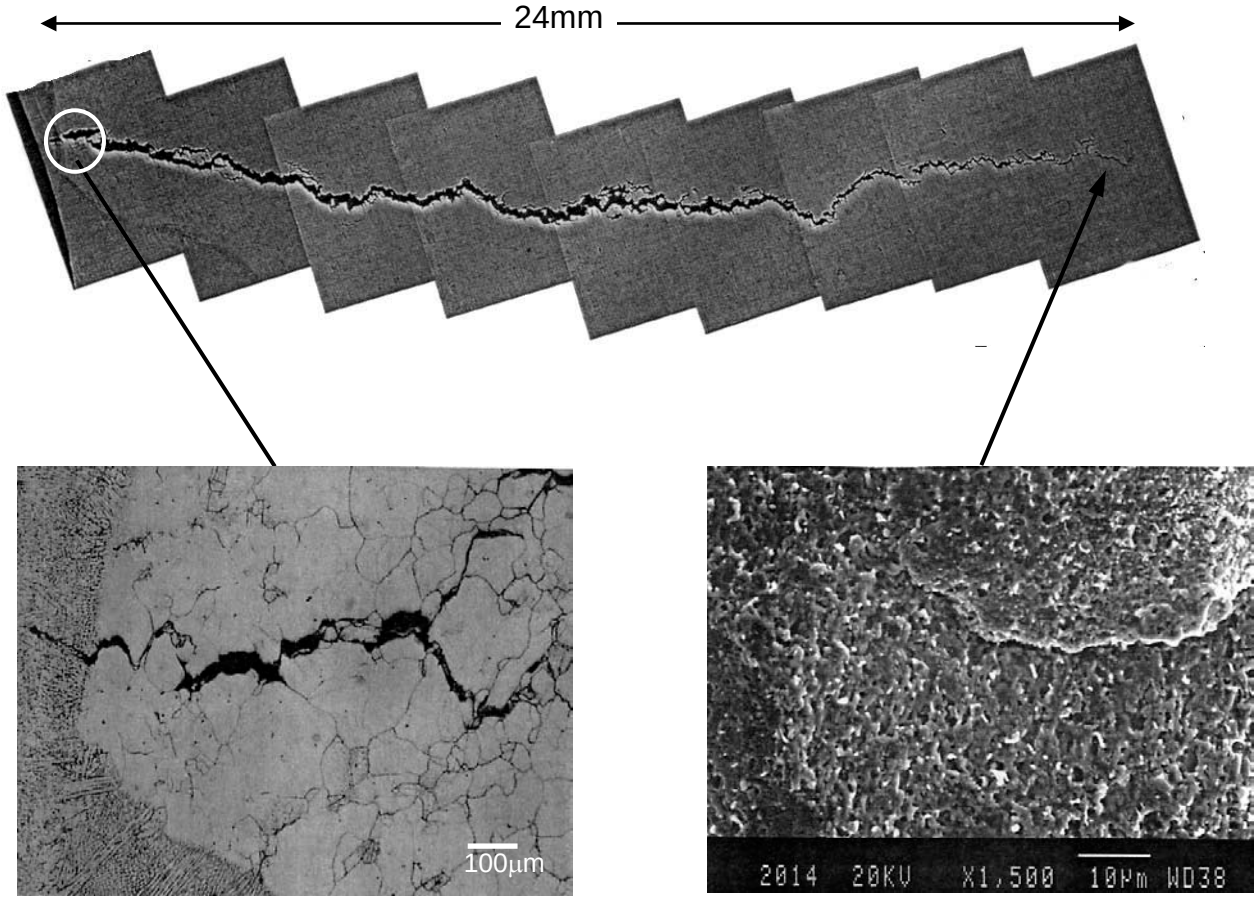
Requirements:

1: Creep cavitation only occurs under hydrostatic stresses so must study thick samples which requires good penetration

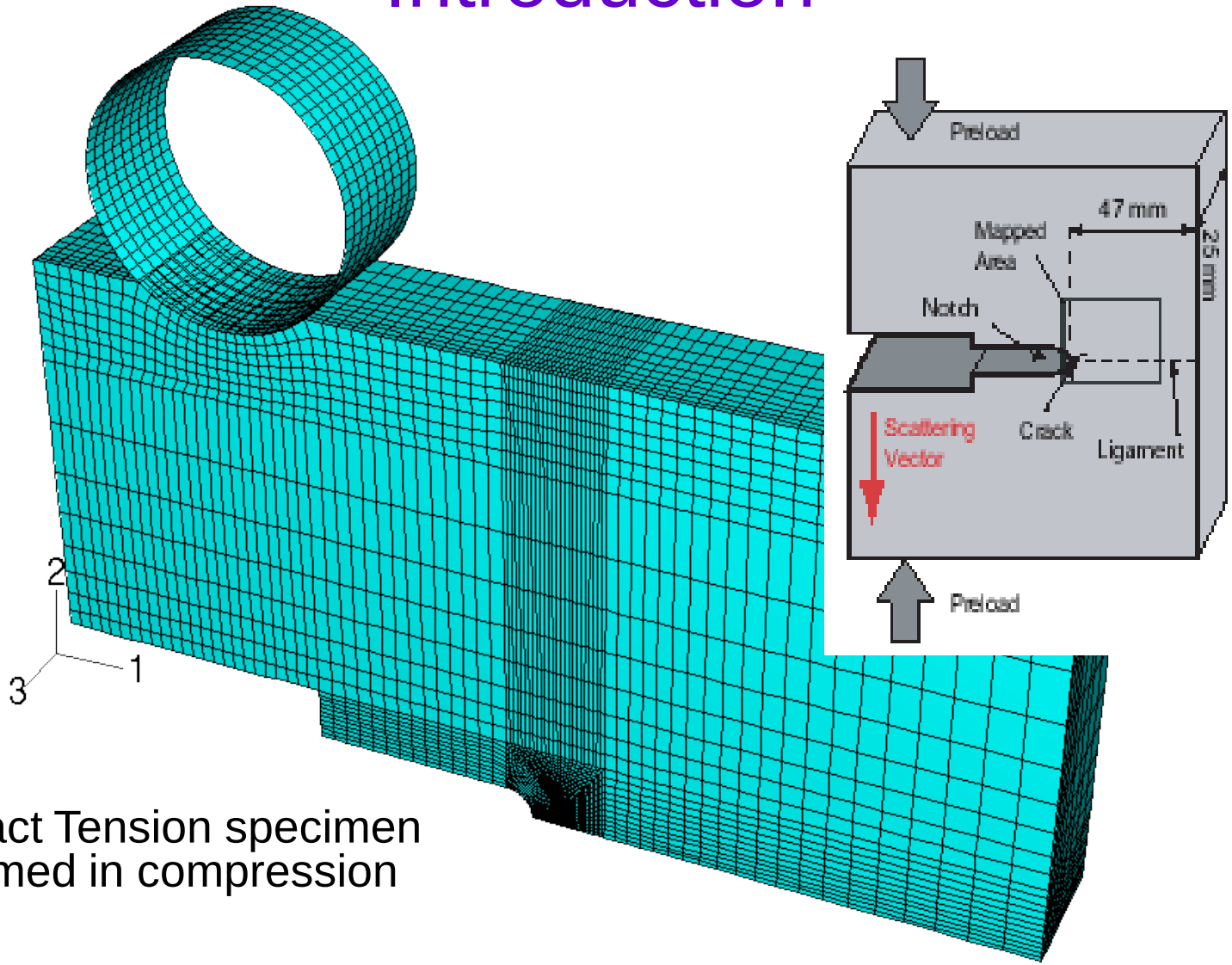
2: Need to be able to follow stress development over time.

Residual stress driven failure

Creep Cavities nucleate under triaxial stress join up to form a life-limiting crack

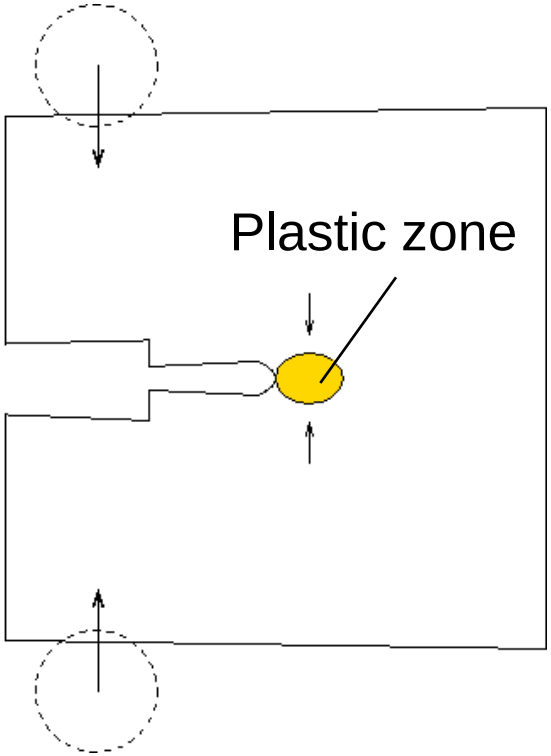


3D FE of Residual Stress Introduction

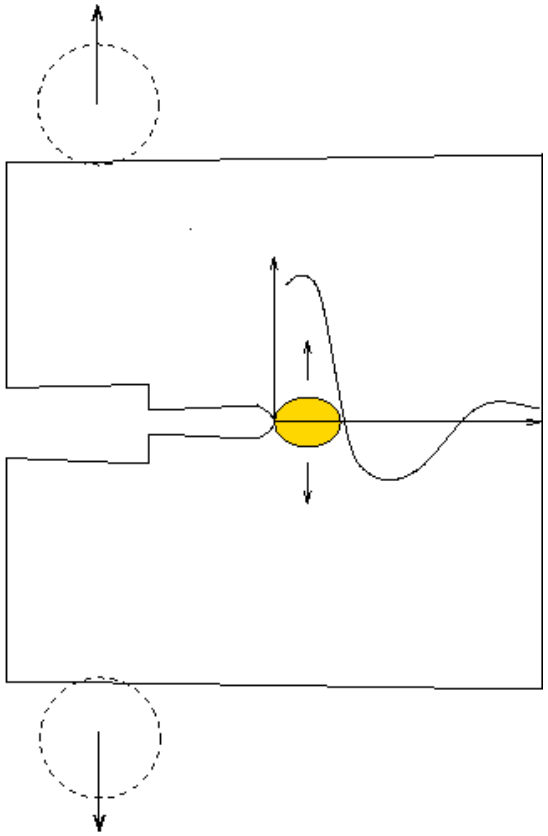


Compact Tension specimen deformed in compression

CT deformation

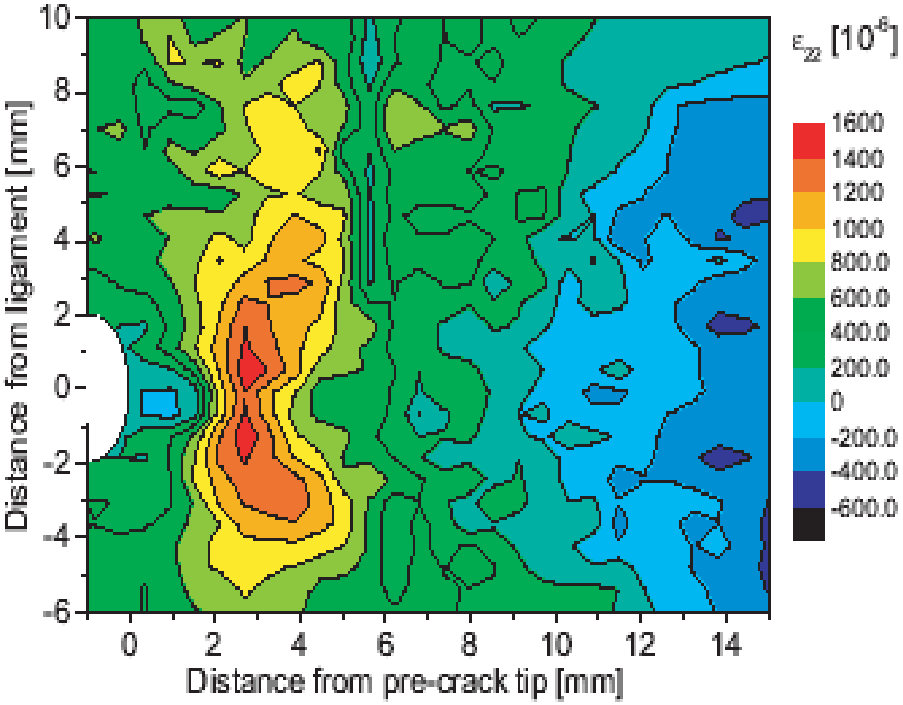


Deformation of CT

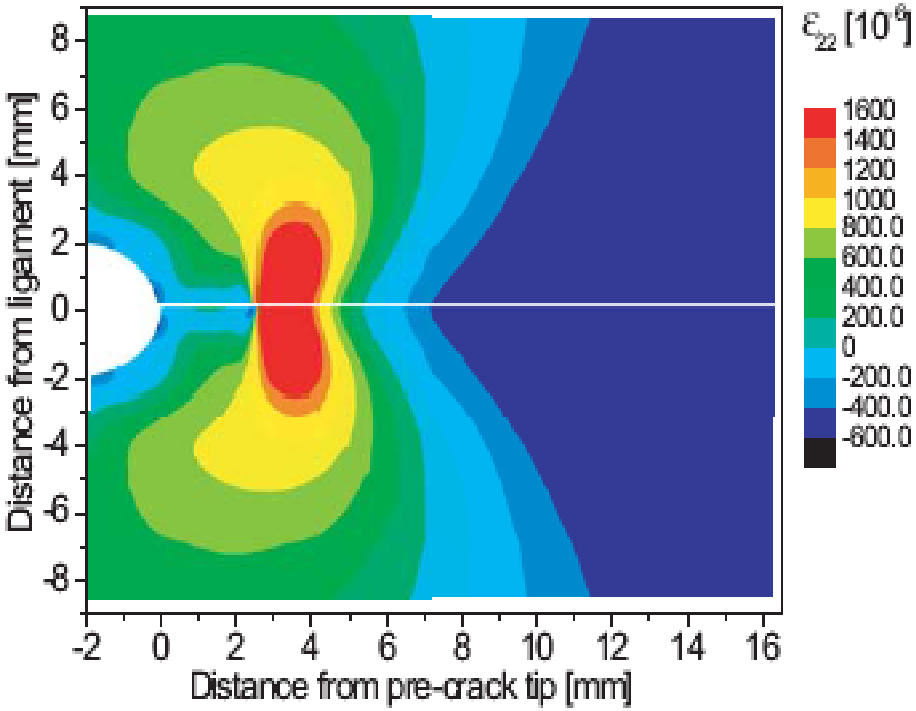


Residual stress formed after unload

Measured and predicted residual stress fields at pre-cracked notch at ESRF

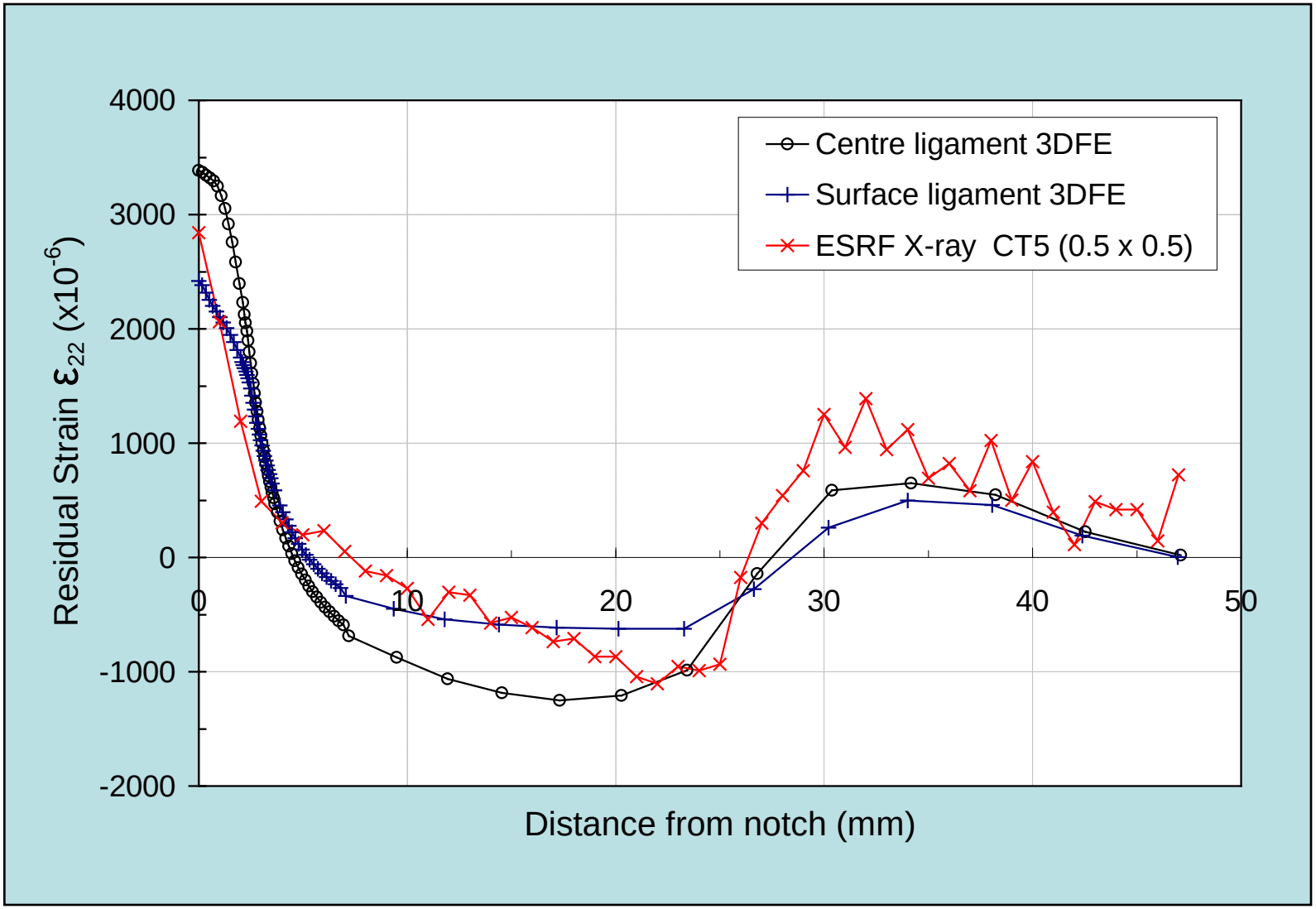


Hard X-rays (ID15)

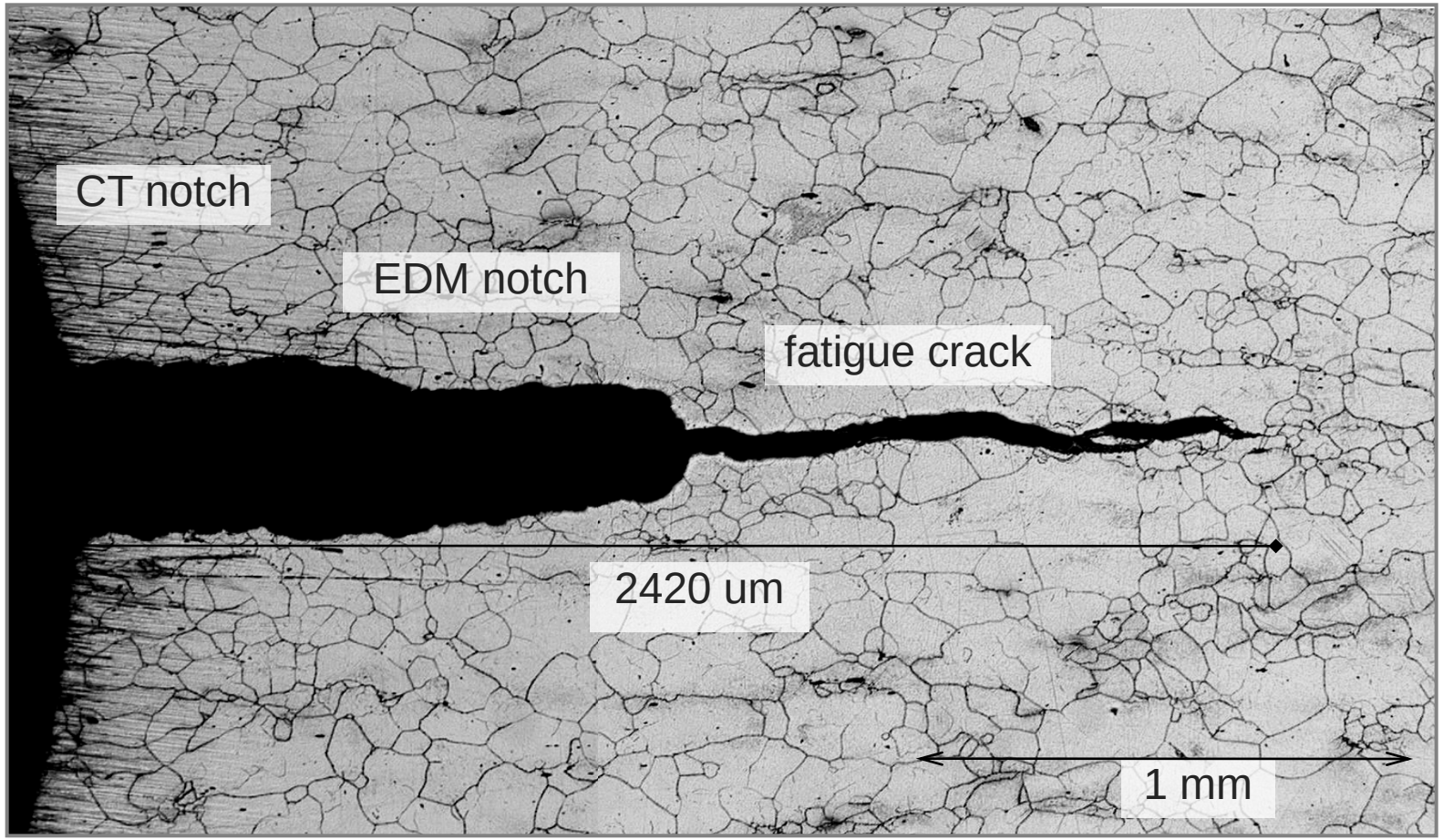


FE model

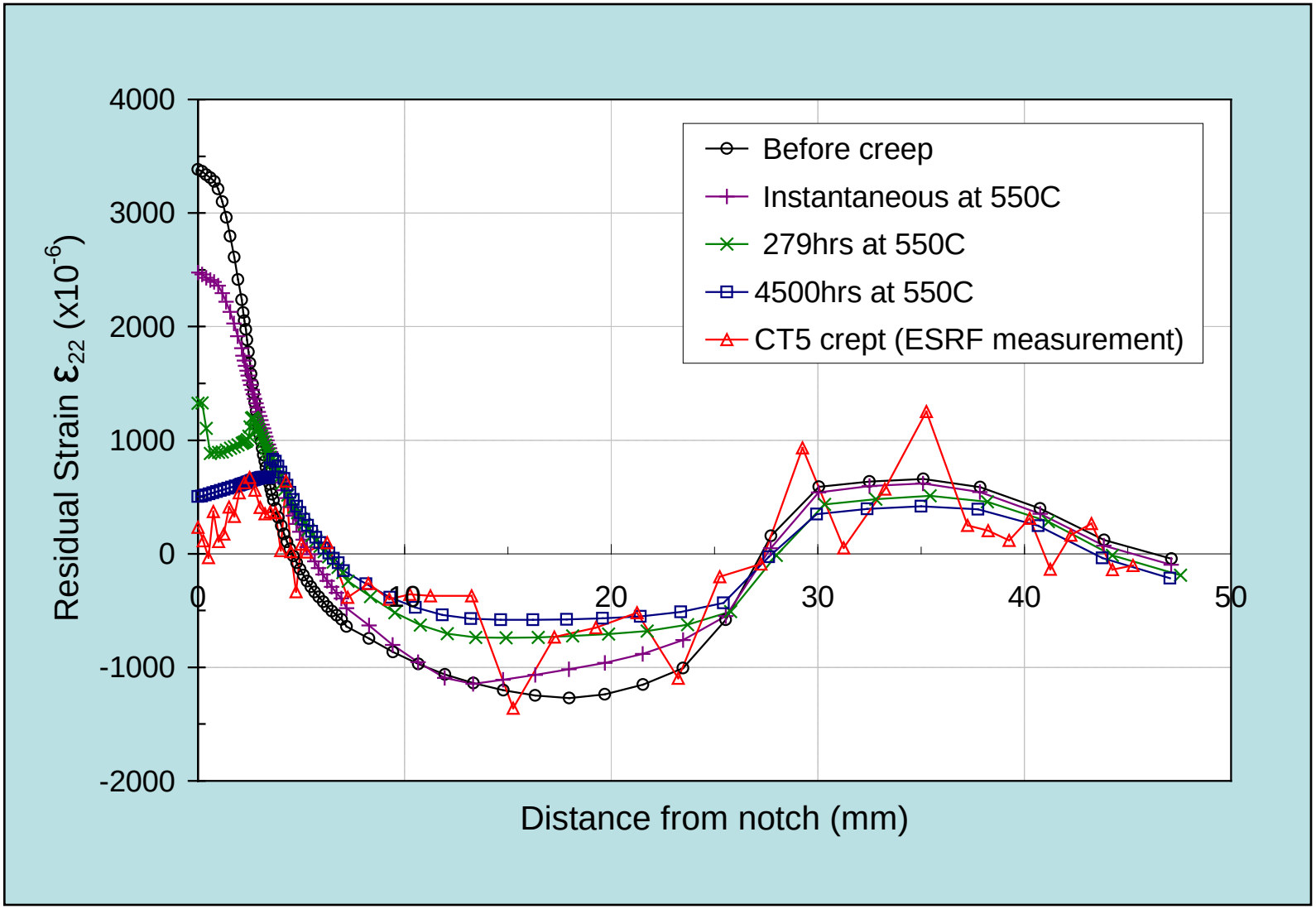
3D FE vs measurements



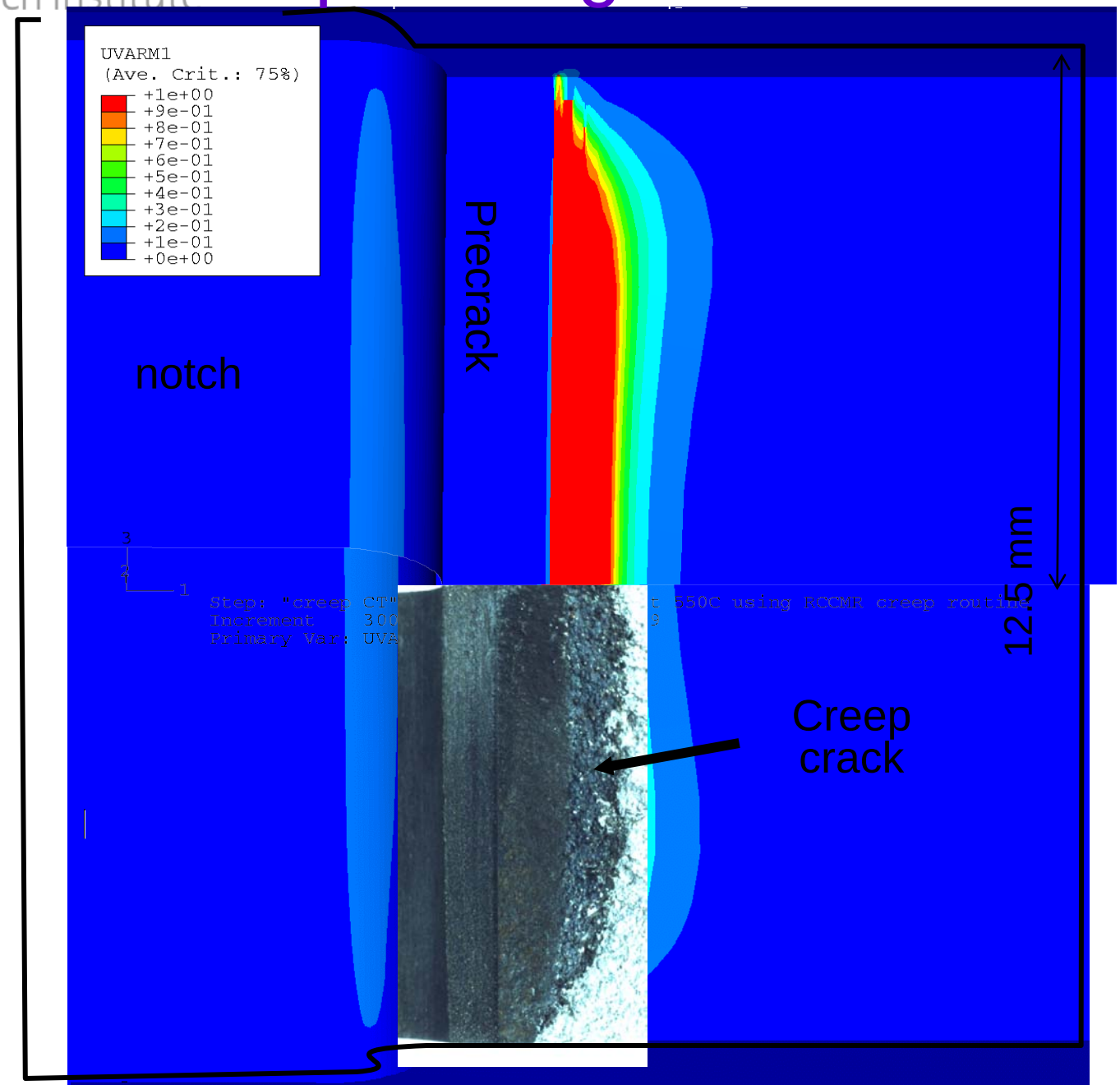
CT1 after creep (4500hrs at 550C)



During thermal exposure



Creep damage after 43hrs



Summary

- Vulcan could penetrate deep inside welds to map the evolution of residual stress with creep cavitation
- Help to underpin FE Damage models for predicting life extension of aging nuclear plant

Exemplar 2: Smart weld fillers

Aim:

To design fillers that can lower, remove or reverse sign of weld residual stress

Requirements:

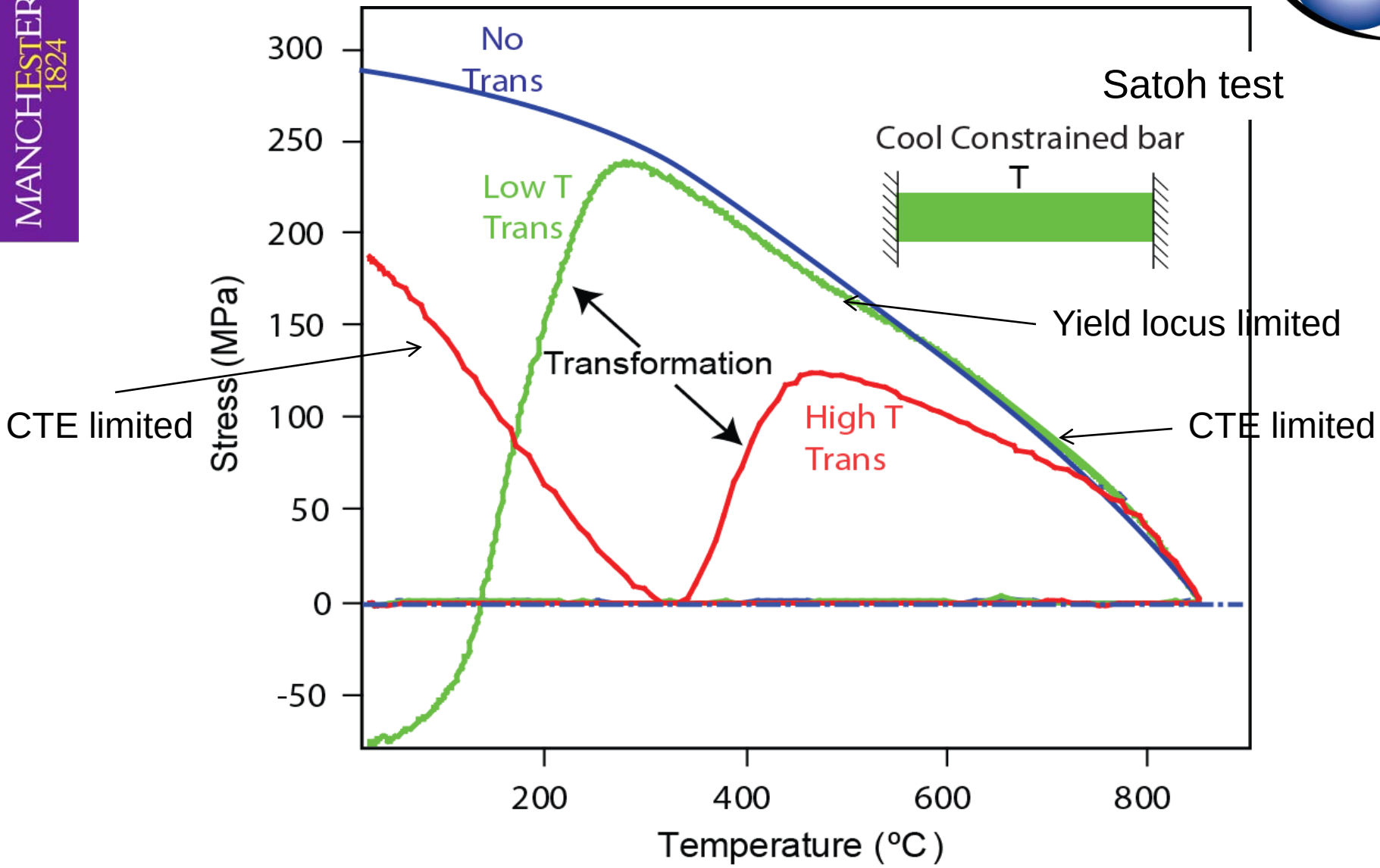
1: fast scanning to see how changing transformation temperature affects weld stress

2: Area scanning to map welded components

Aim: to design a low matensite transformation temp, but tough, stainless steel

CamAlloy 4	0.01C 13Cr 6Ni 1.5Mn 0.06Mo 0.73Si	Martensite with small additions of Ferrite and Austenite
OK Tubrod 14.20	0.03C 0.8Si 1.2Mn 19.5Cr 10.0Ni	Austenitic with some ferrite content

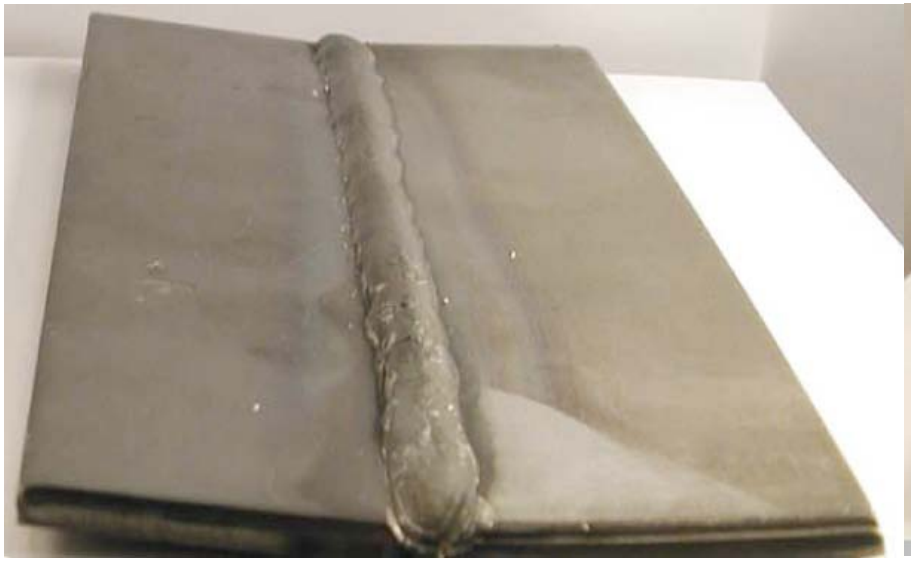
Constrained cooling



- Reducing stress by lowering transformation temperature

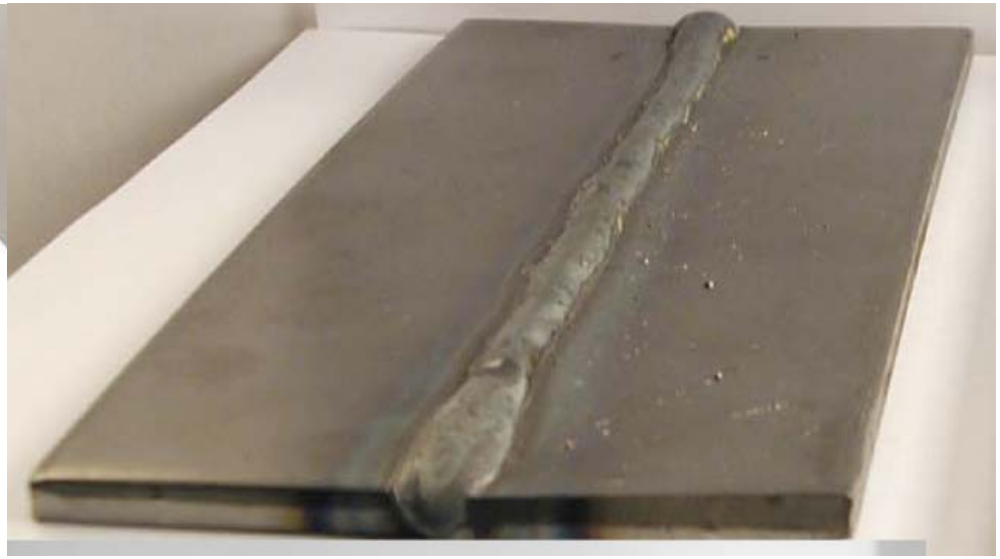
Distortion on mock-up half depth V welds

Tubrod 14.20



Non transforming
7° Distortion

Cam4 Alloy



Low T Transforming
2° Distortion

Studying weld stress development in situ

- To control the residual stress need to study transformation under welding conditions
  - Fast cooling rates
  - Constrained conditions
- Synchrotron diffraction is sufficiently quick, but welds notoriously difficult to study in situ
  - difficult to know temperature and stress at measurement location in a weld
- Since stresses only introduced during cooling in the **solid state**
  - maybe better to simulate weld cooling in a thermo-mechanical simulator under controlled conditions

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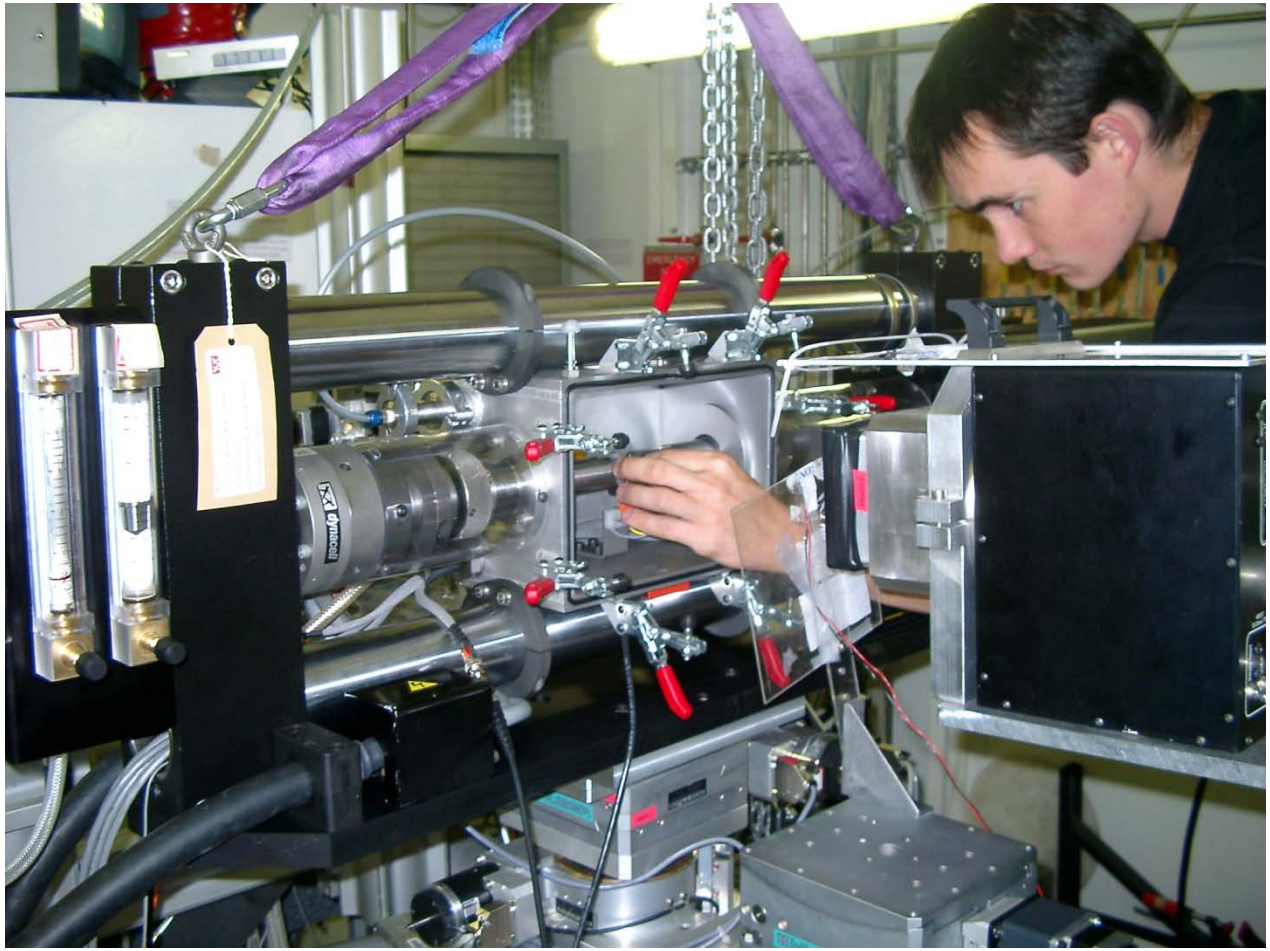
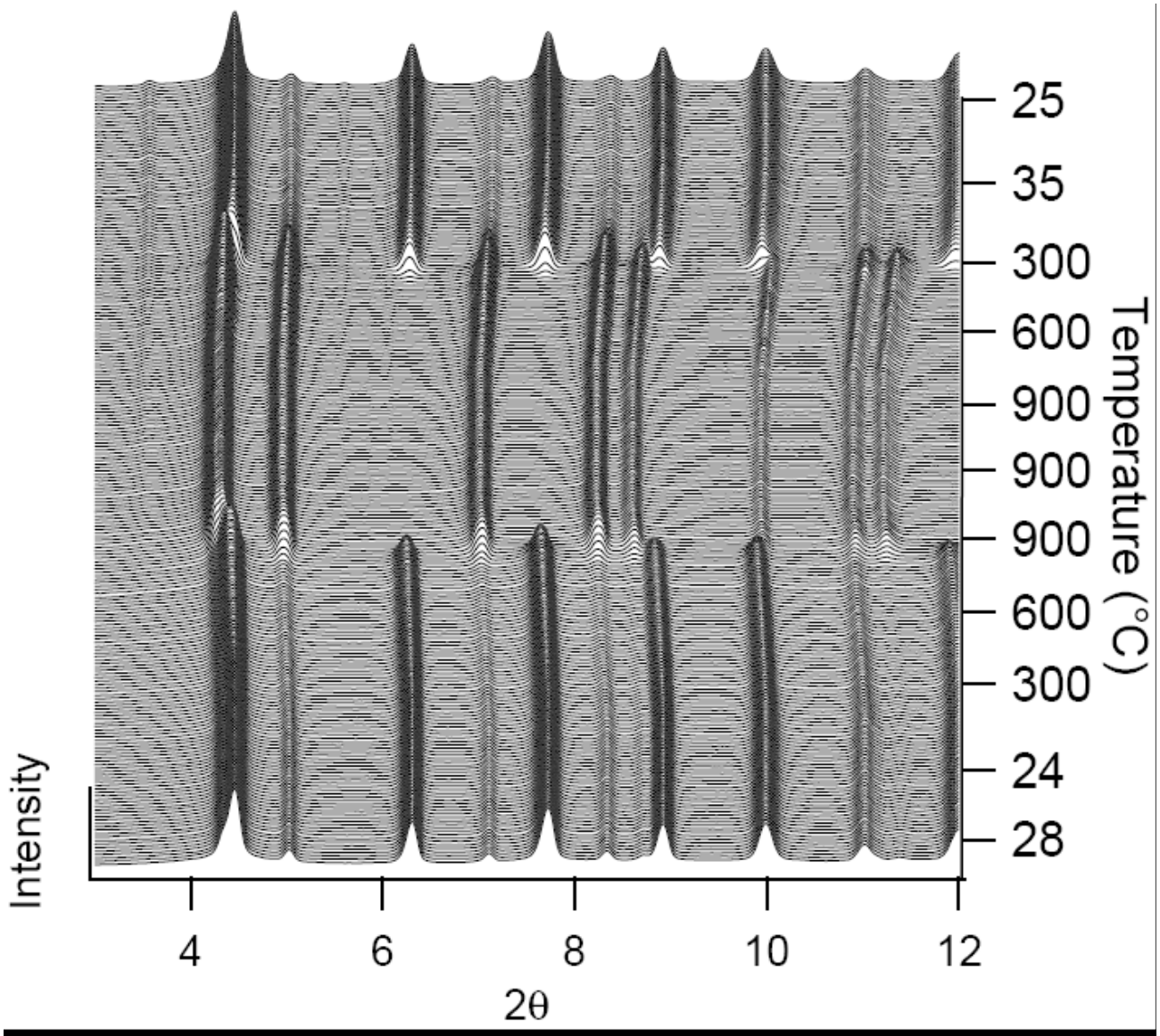
Experimental setup for in-situ monitoring

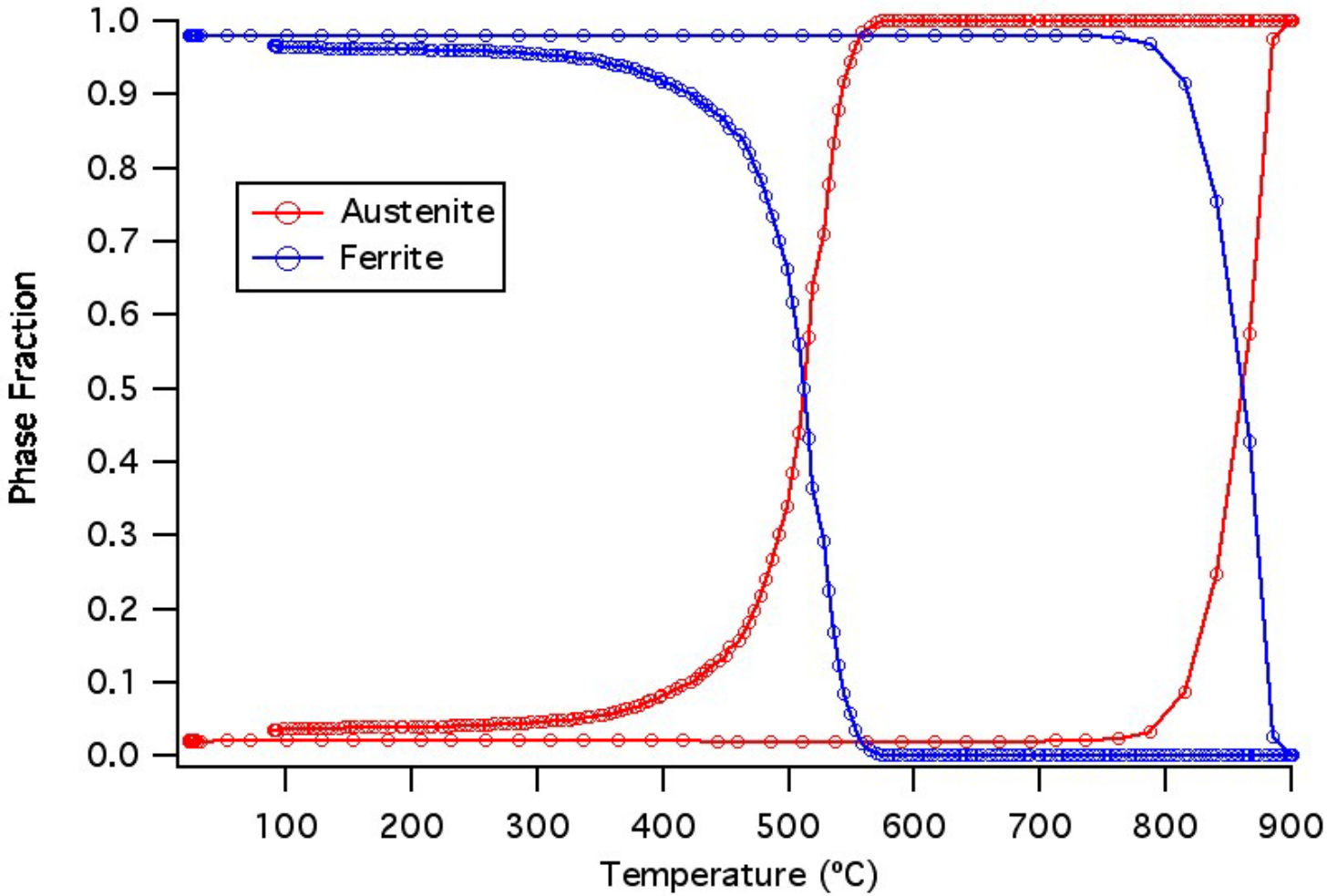


- ExperimETMT had resistive heating sits on ID11 beamline at the European synchrotron facility

Monitoring phase transformations under representative cooling rates



Evolution of phase fractions



- Full structural (Rietveld) refinement of the diffraction patterns to obtain phase fractions

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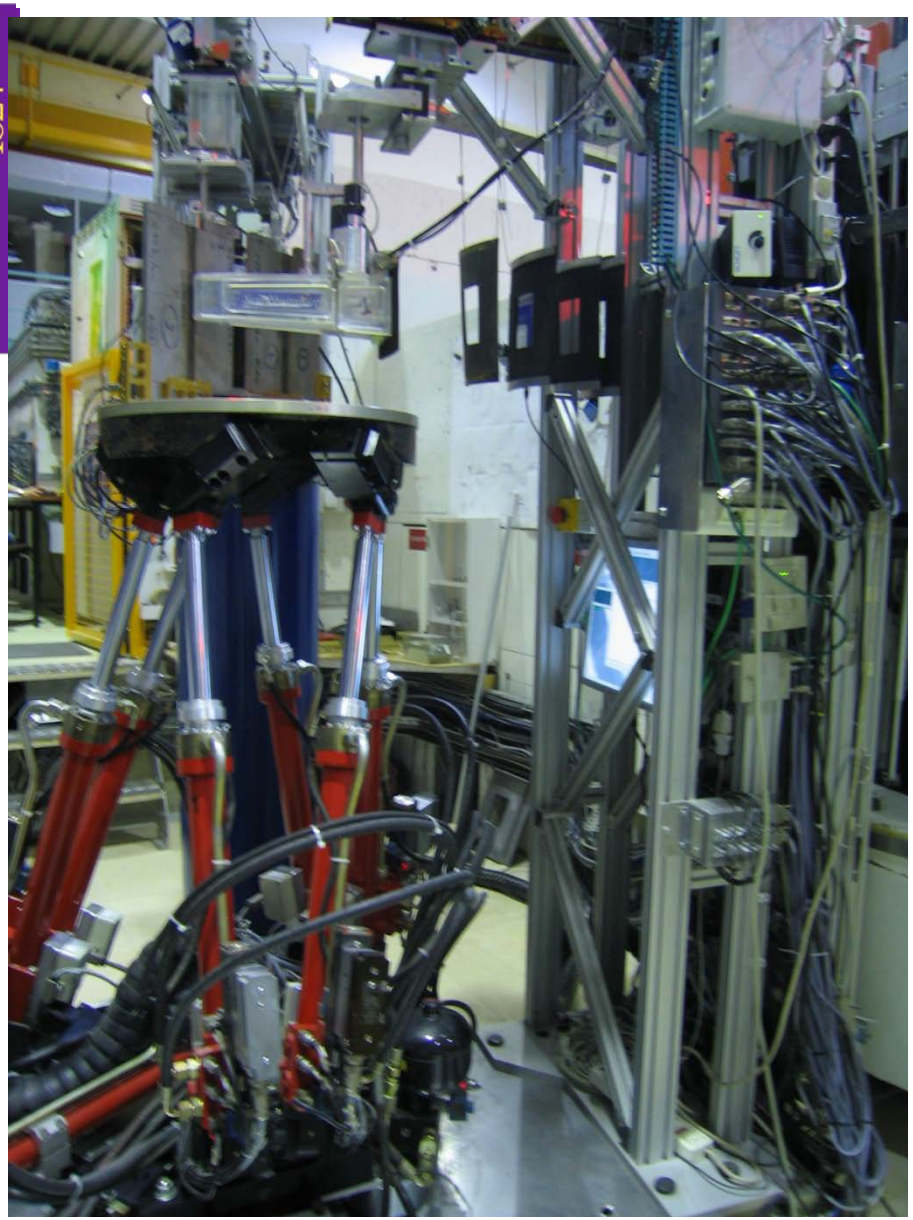

Residual stress measurements at SALSA, ILL

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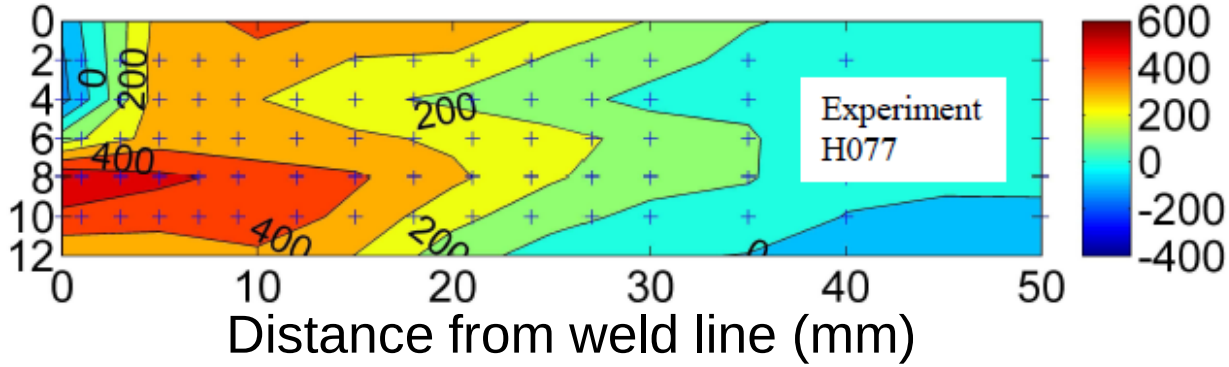
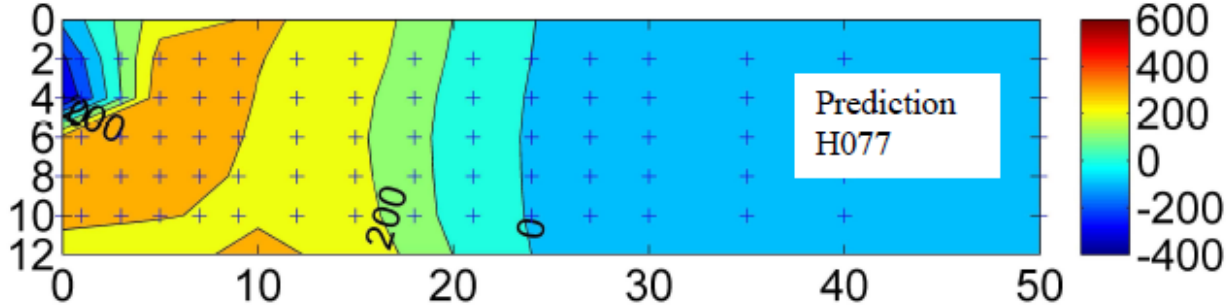
Measured and predicted residual stresses

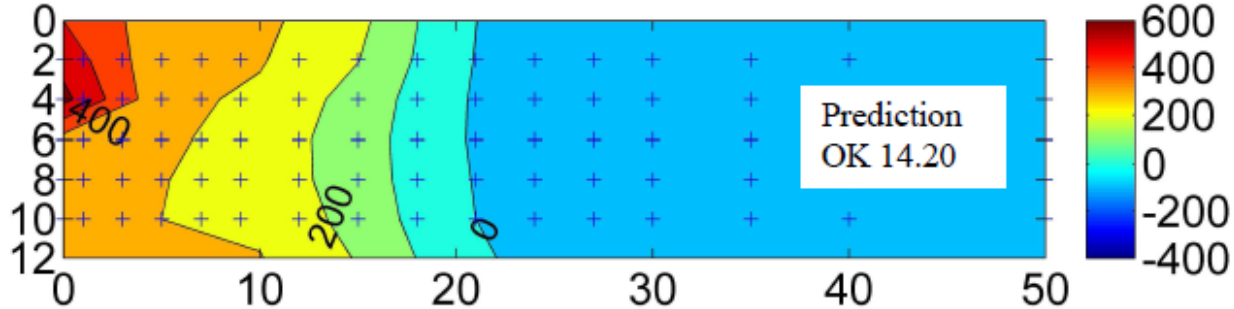
Smart Filler



Smart Filler



Austentic Filler



Summary

- Smart fillers enable one to engineer the weld stress state
- Need fast measurements to see performance of weld filler
- Need neutrons to problem large structures, such as nuclear plant, where PWHT not an option and smart fillers needed

Exemplar 3: From prototype to full scale test

Aim:

To develop welding procedures on small samples and transfer them to full-scale components

Requirements:

1: Needs to accommodate large samples

2: Need high penetration/mapping

Inertia Welder

Rolls-Royce

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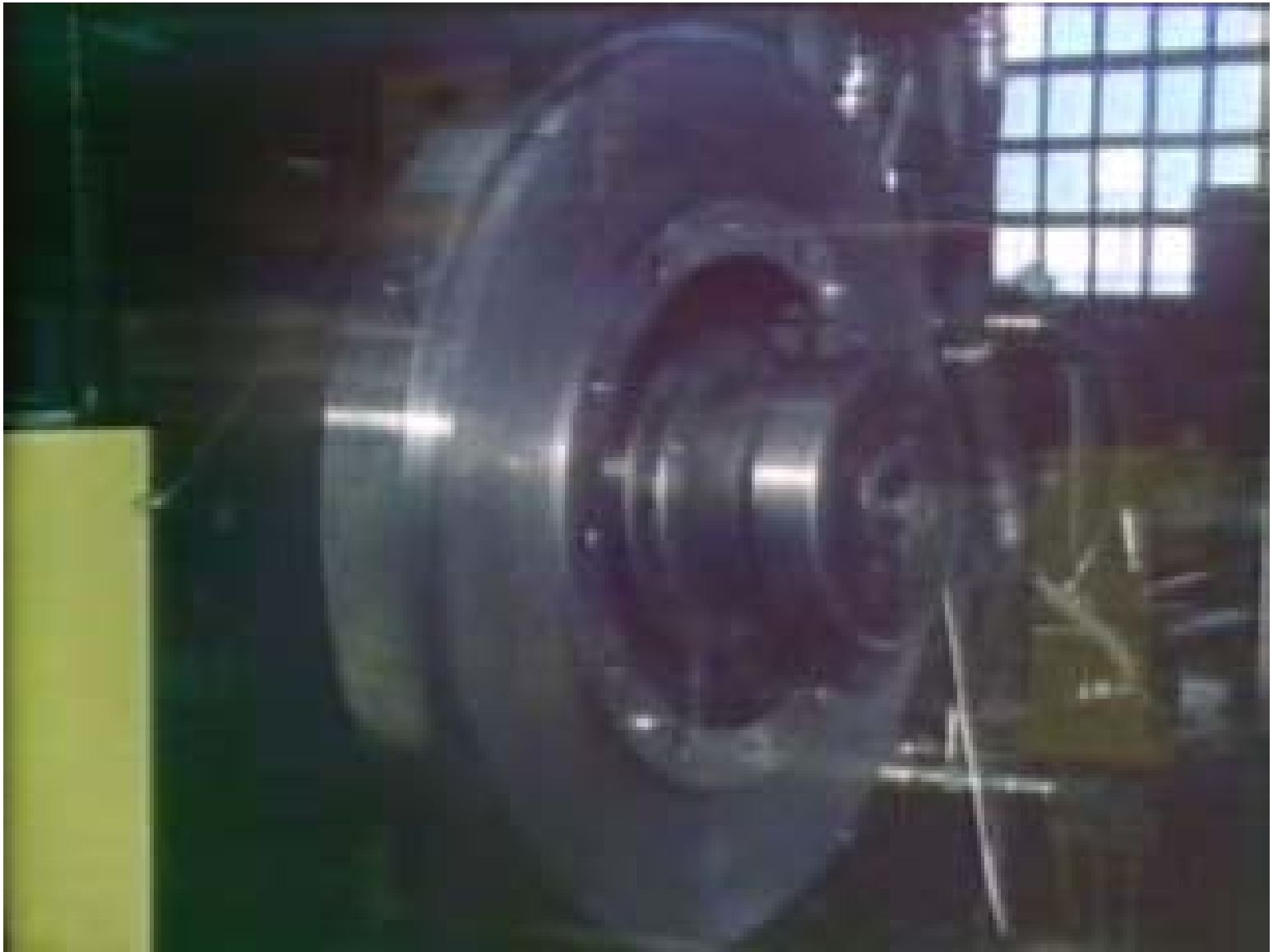
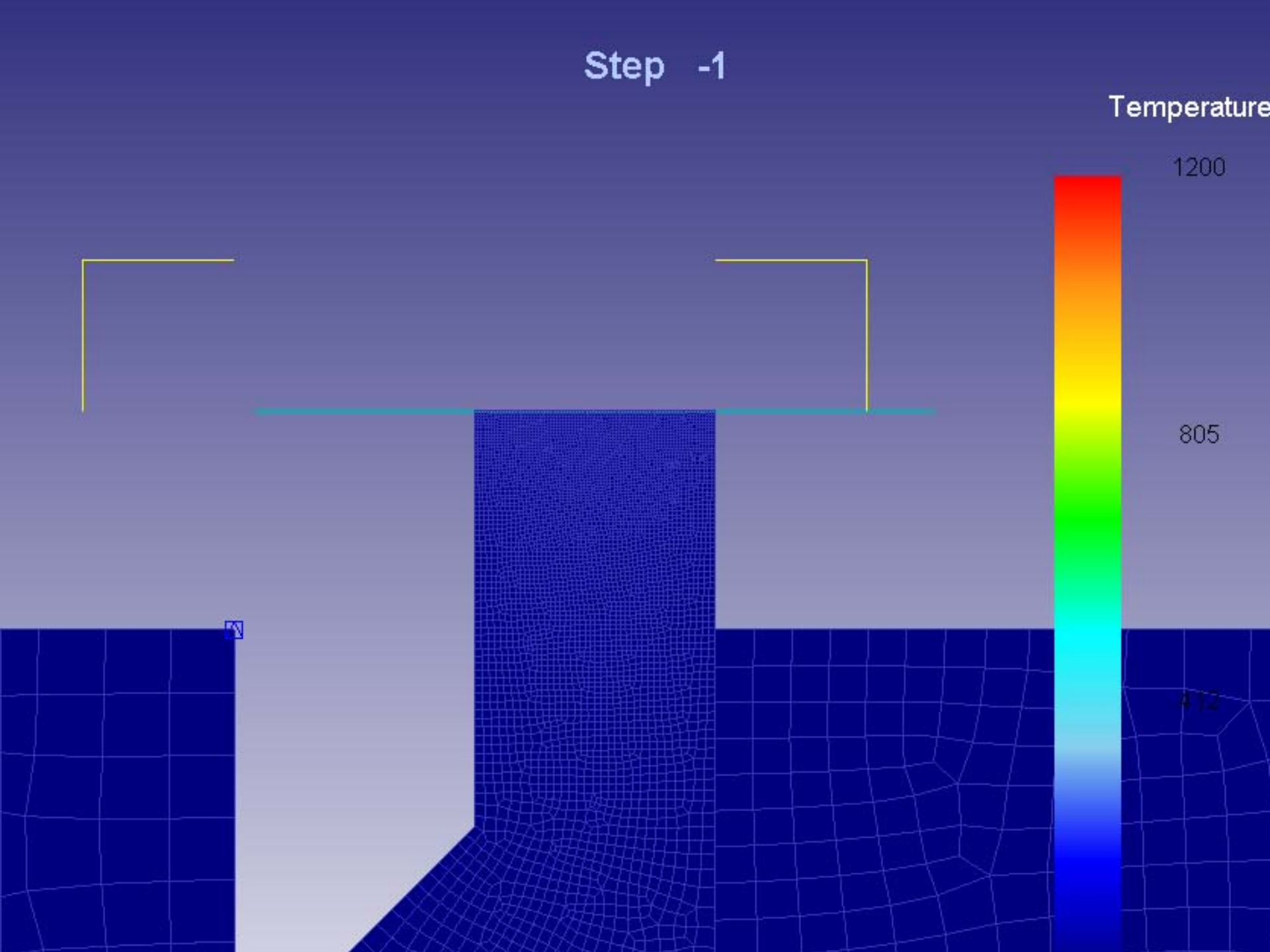
Inertia friction welding of aeroengine discs




Step -1
Temperature
1200
805
412

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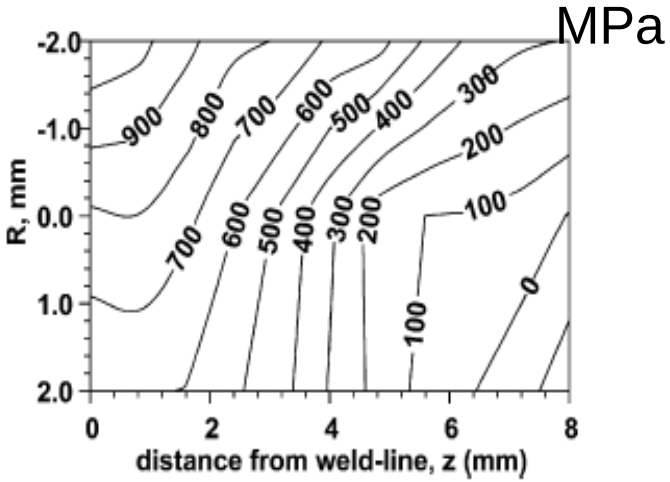
Weld development on sub-scale prototypes

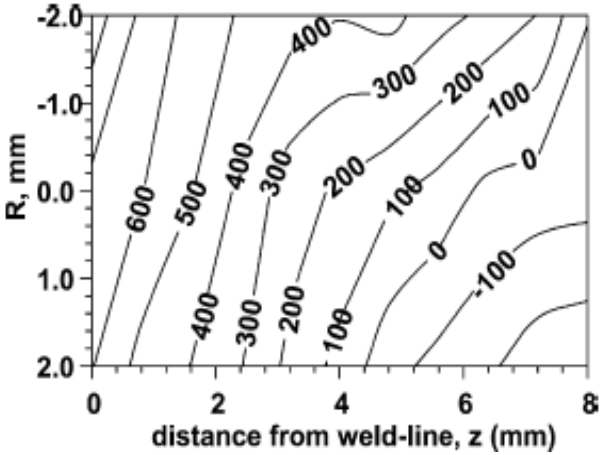
- Weld stresses measured by neutron diffraction on prototype
- Optimal welding and post weld heat treatment conditions identified

140mm test-piece

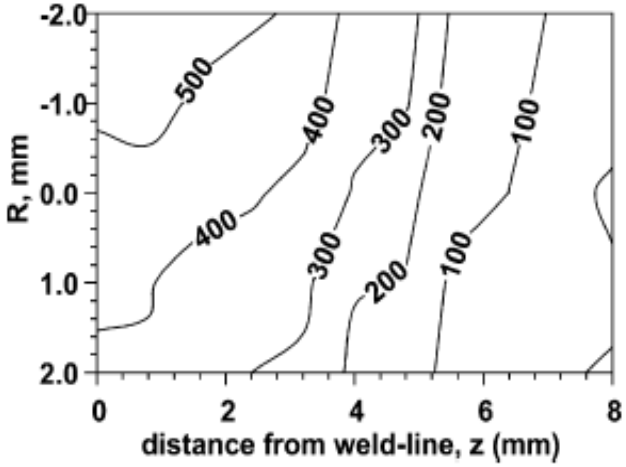
As-welded



Usual post weld heat treatment

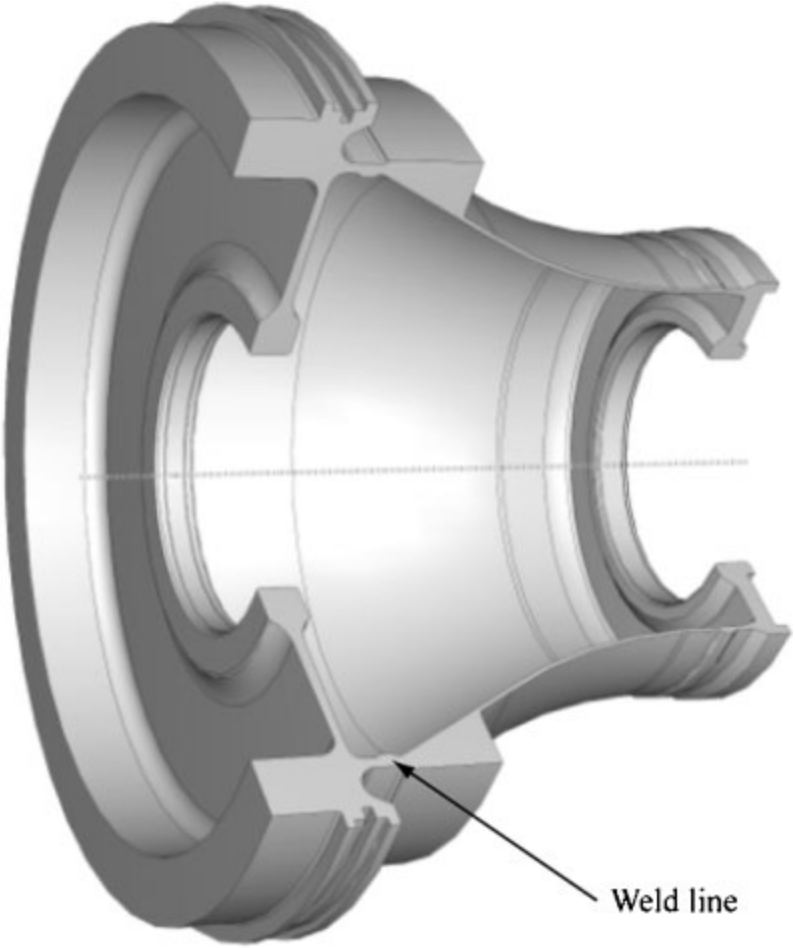


New PWHT



Extension to full-scale disk assemblies

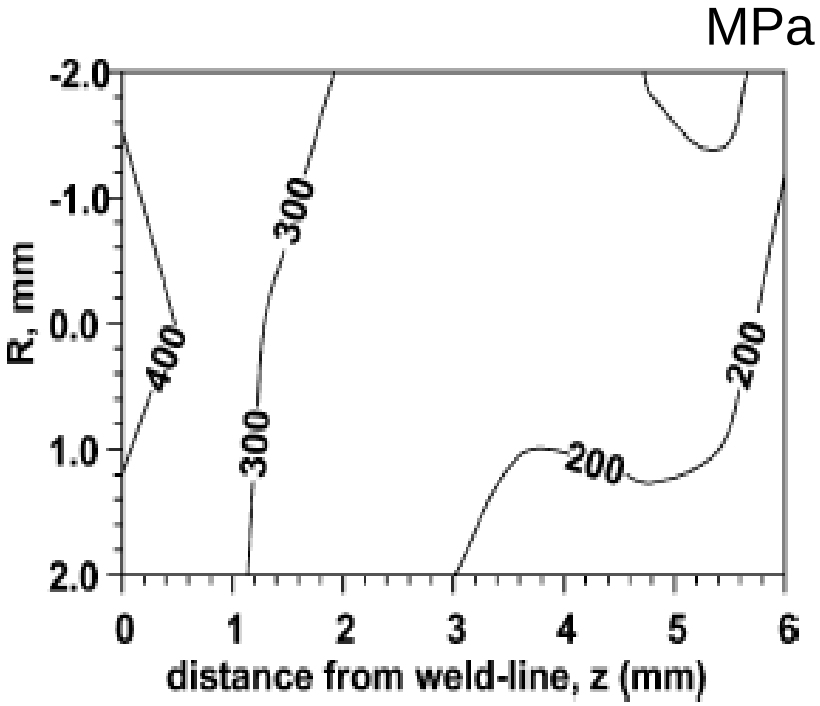
Can procedures developed on sub-scale prototypes be applied directly to full size (600mm) aeroengine assemblies?



Extension to full-scale disk assemblies

Actual 600mm assembly

New treatment



Optimised weld procedure and PWHT give very low stresses

Conclusions

- Welds were amongst the first components studied by neutron diffraction 25 years ago
- Welds continue to be an area of concern
- Innovative strategies can be taken from concept to optimised solution using neutron diffraction
- Vulcan will be able to tackle
  - Large samples
  - In situ welding experiments
  - Following stresses through life
  - Developing and optimising innovative solutions
  - Validating FE element models for predicting weld lives

Postscript

- Synchrotron strain measurement is a useful complement to neutron strain work.
- High spatial resolution often touted as a significant benefit, but the much greater divergence and acceptance angles associated with neutron diffraction mean that grain size rarely a problem, whereas it often limits the size of the gauge using synchrotron X-rays.