Residual stress effects on the fracture toughness of a narrow-gap girth welded pipe

Rob McCluskey

Universities Nuclear Technology Forum 2011

University of Huddersfield

13th April 2011

Background

PhD course funded by Serco Technical Services
Started September 2008, currently in 3rd year of project

Academic Supervisors:	Prof. Andrew Sherry Dr. Martin Goldthorpe
Industrial Supervisor:	Mr. John Sharples, Serco Technical Services
Group:	Structural Integrity Group, Materials Performance Centre (MPC), University of Manchester

Weld residual stresses

- Girth-butt welds join sections of stainless steel pipe in primary circuit of PWRs - can be up to 6,000 in a typical civil reactor

- The welding process introduces complexities:
  - Sections resist being joined together
  - Contraction on cooling of weld and parent material creates a residual stress field around the weld

- Structural integrity issues: residual stresses combine with service loads
  - Structure becomes more susceptible to failure:
    - Fracture
    - Fatigue
    - Stress Corrosion Cracking (SCC)

- Residual stresses are influenced by geometry
  - Can be as high as the material yield stress


www.esab.com/global/en/news/image-archive.cfm

Residual stress and defects

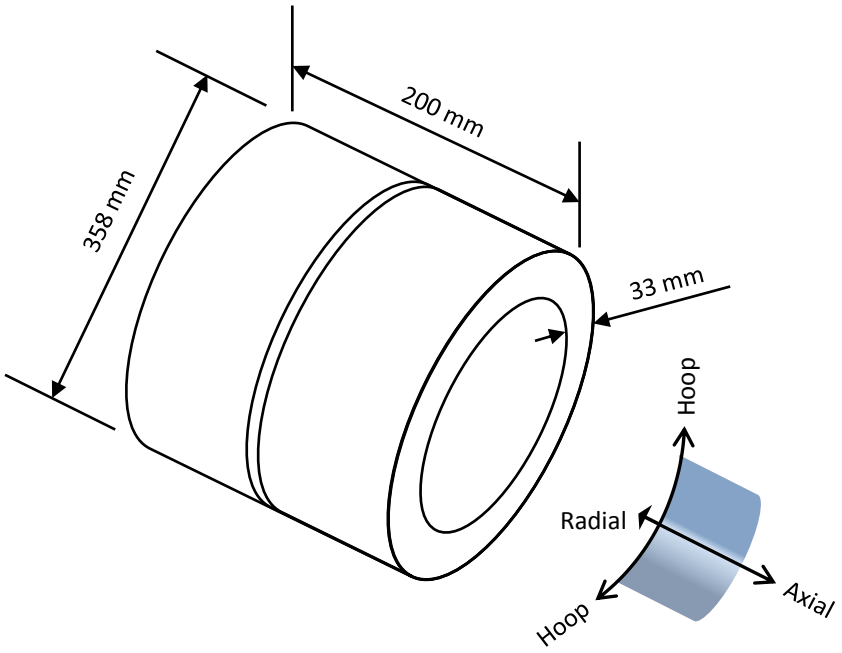
- When a defect is present, residual stresses can drive the mechanisms behind failure

- Procedures have been developed that incorporate primary and residual stresses on the behaviour of a defect in a structure
    - Safety margins can be quantified, justifications can be made to keep plant operating safely

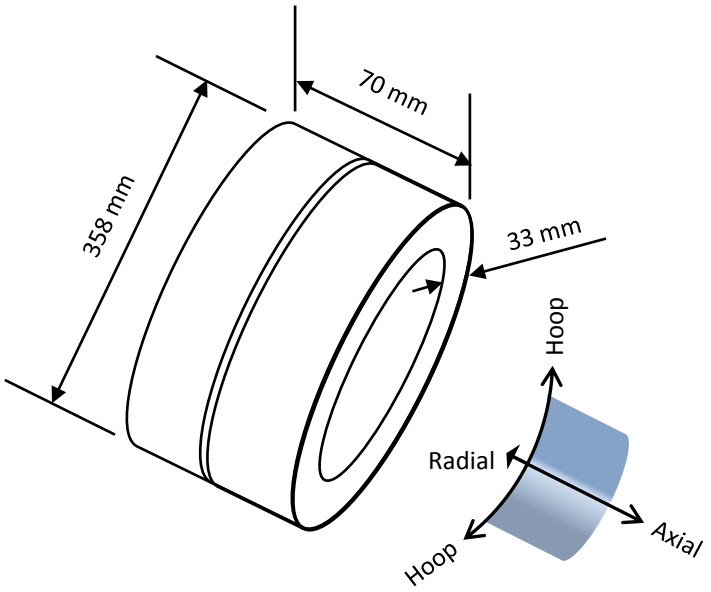
- A typical failure assessment requires several parameters to be determined, such as:
    - Stress intensity factor, K_I
        - Load applied to the structure, K_I^P
        - Residual stress contribution, K_I^S
    - Plastic limit load of structure
    - Fracture toughness of material, K_{Ic} or K_{mat}

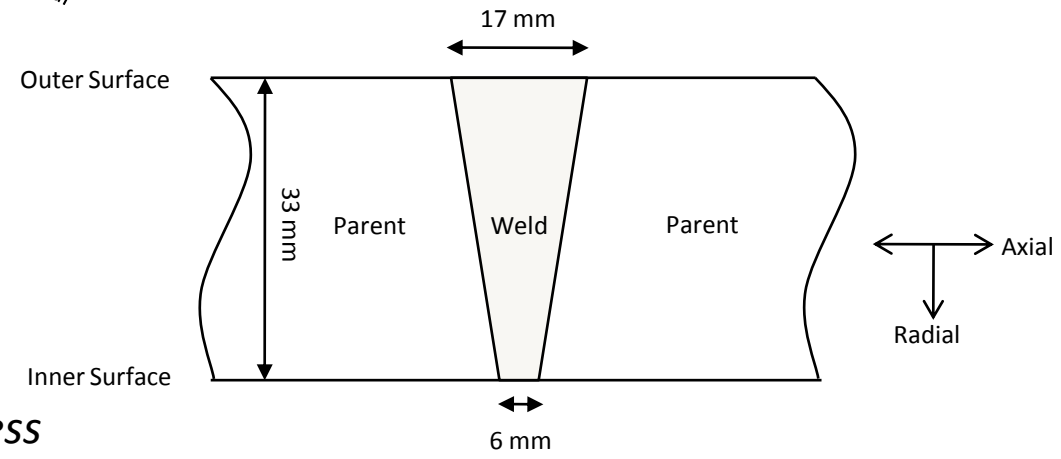
As-received material: narrow-gap girth-butt weld

Long section of pipe



Short section of pipe





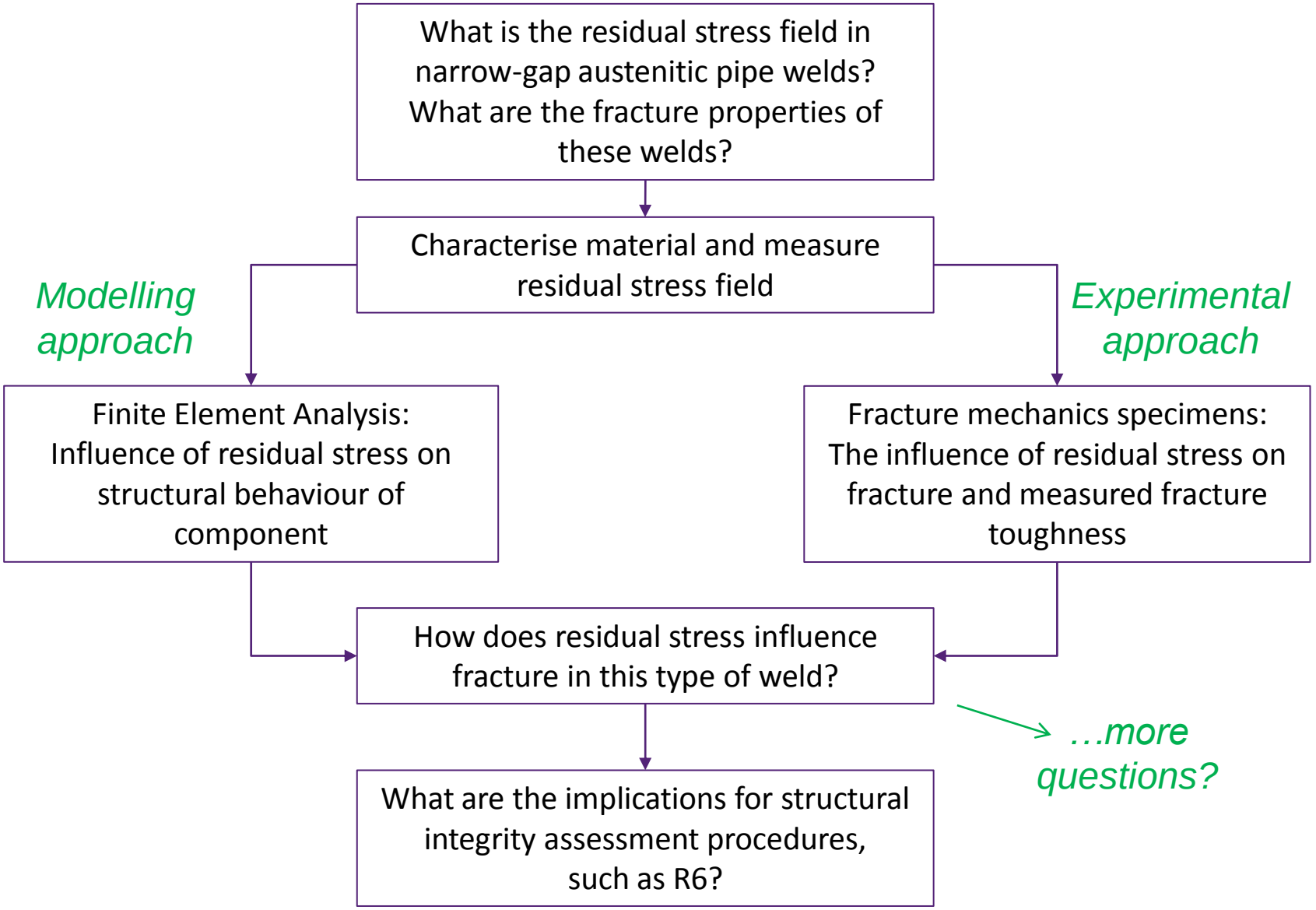
Material

Parent: 304-stainless steel

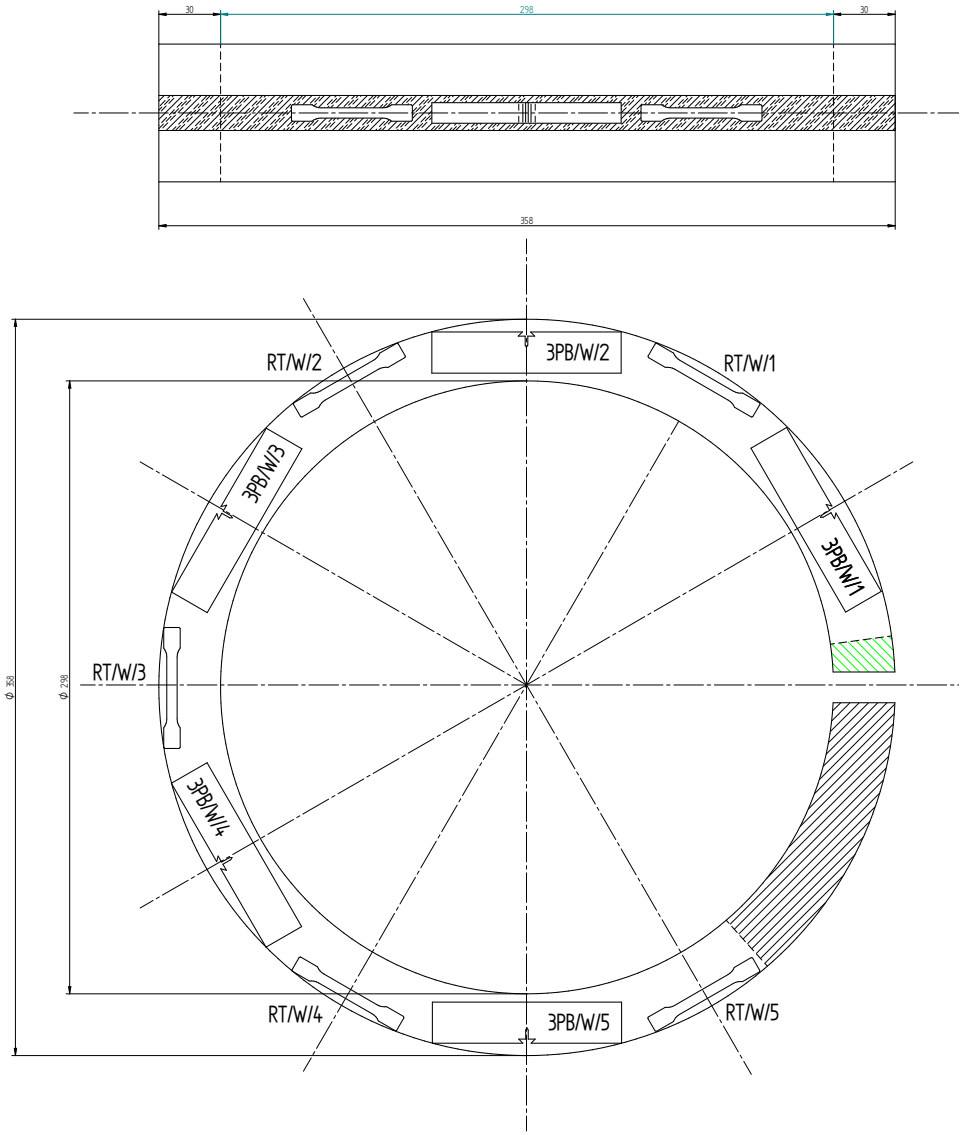
Weld: 308L-stainless steel

Supplied by BAE Systems, Barrow-in-Furness

Project map

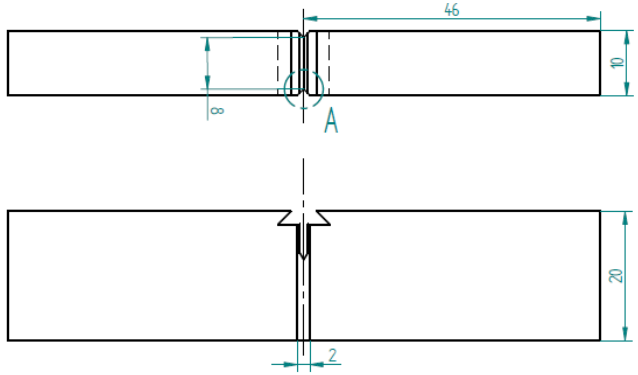

What is the residual stress field in narrow-gap austenitic pipe welds? What are the fracture properties of these welds?
Characterise material and measure residual stress field
Modelling approach
Experimental approach
Finite Element Analysis: Influence of residual stress on structural behaviour of component
Fracture mechanics specimens: The influence of residual stress on fracture and measured fracture toughness
How does residual stress influence fracture in this type of weld?
…more questions?
What are the implications for structural integrity assessment procedures, such as R6?

Mechanical tests: Cutting plan



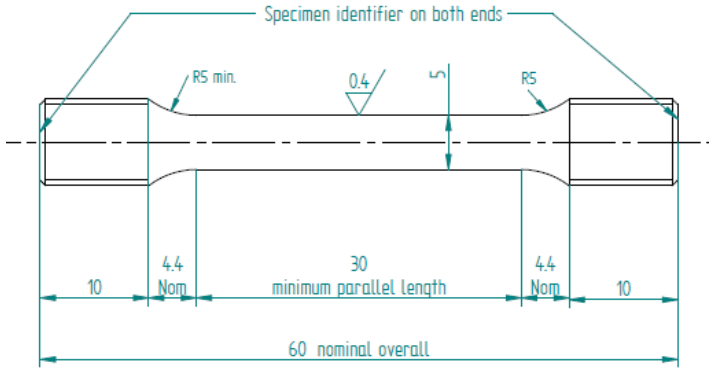
SEN(B) specimen

BS 7448-3 (2005)

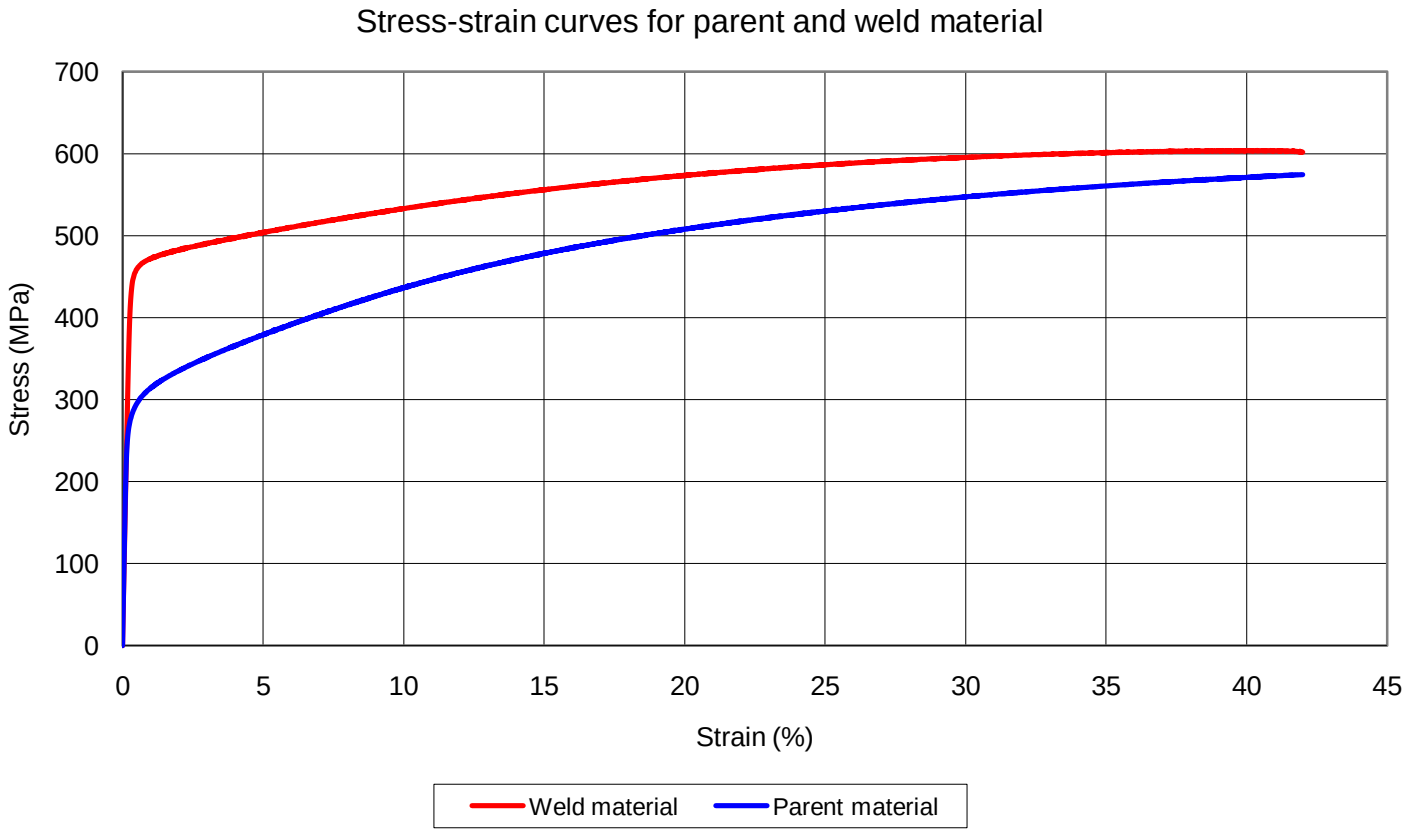


Round tensile specimen

BS EN ISO 6892-1 (2009)

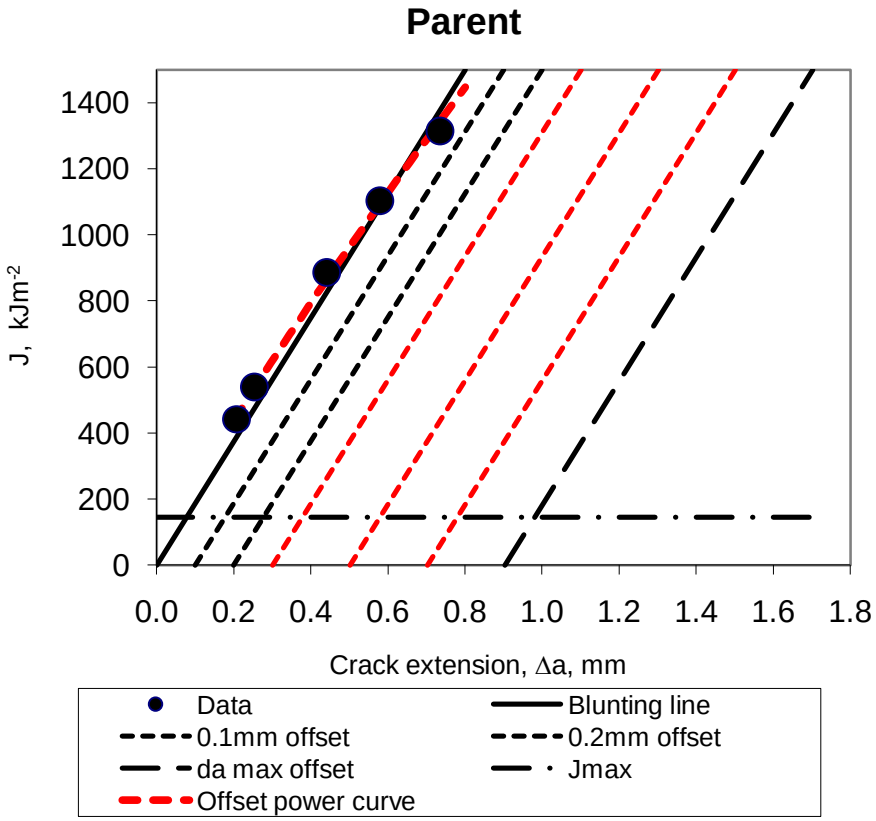


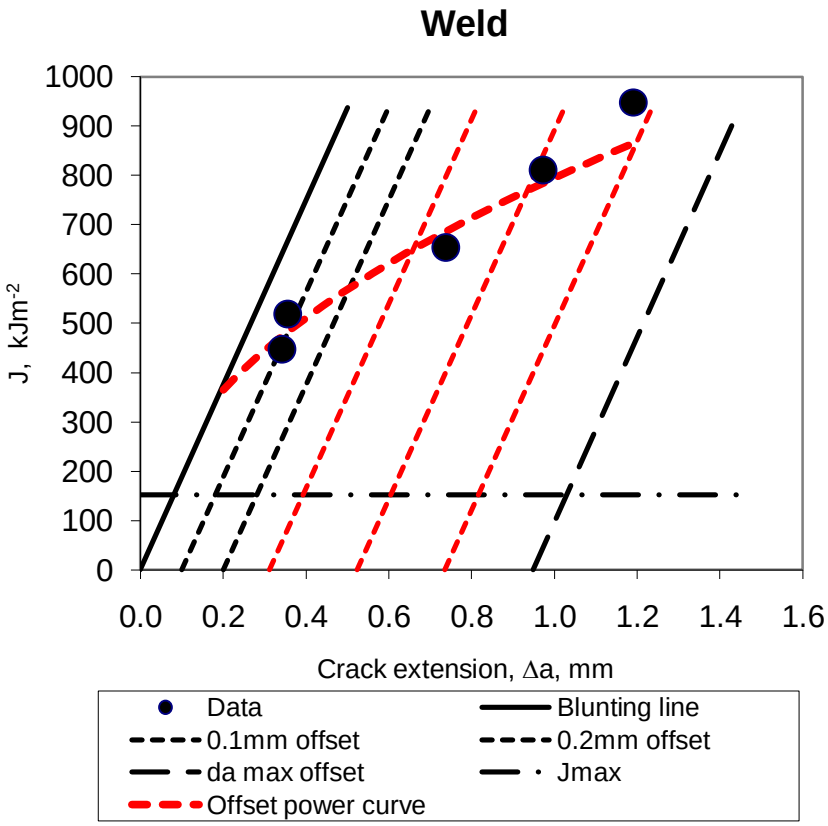
Tensile tests



	Parent – 304 stainless steel	*Weld – 308L stainless steel*
0.2% proof stress (MPa)	284 +/- 16	456 +/- 20
Tensile strength (MPa)	592 +/- 2	605 +/- 10
% Elongation	79	54
% Reduction in Area	84	62

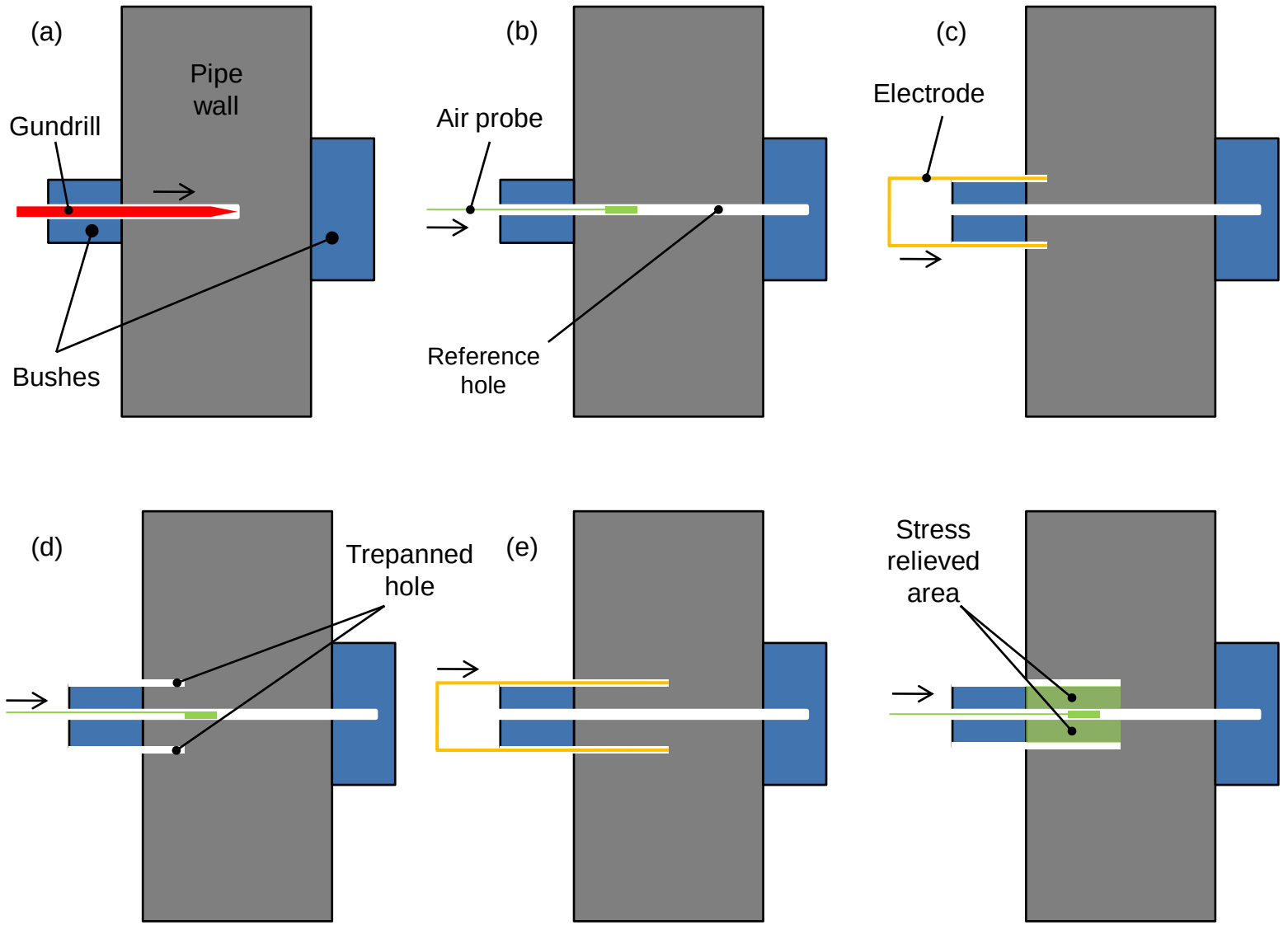
Fracture toughness tests



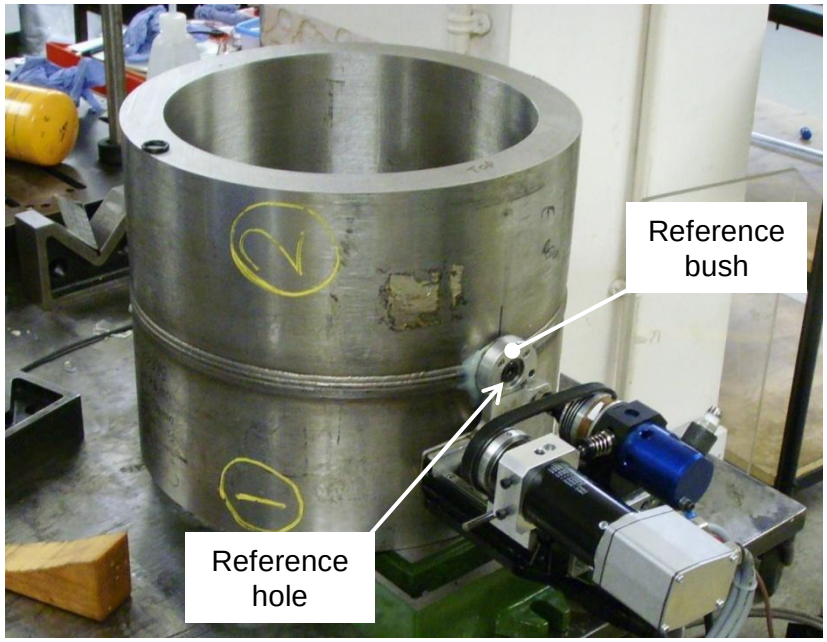


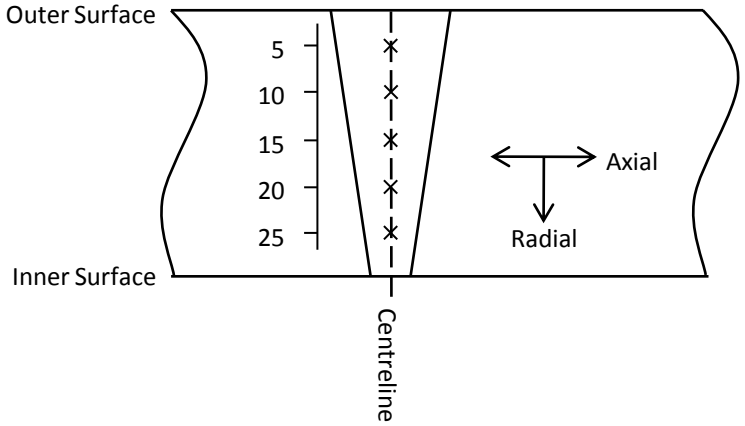
	$J_{0.2}$ (kJ/m^2)	*Equivalent* K_{Jc} *(MPam$^{0.5}$)*
Parent	436	*309*
Weld	366	*283*

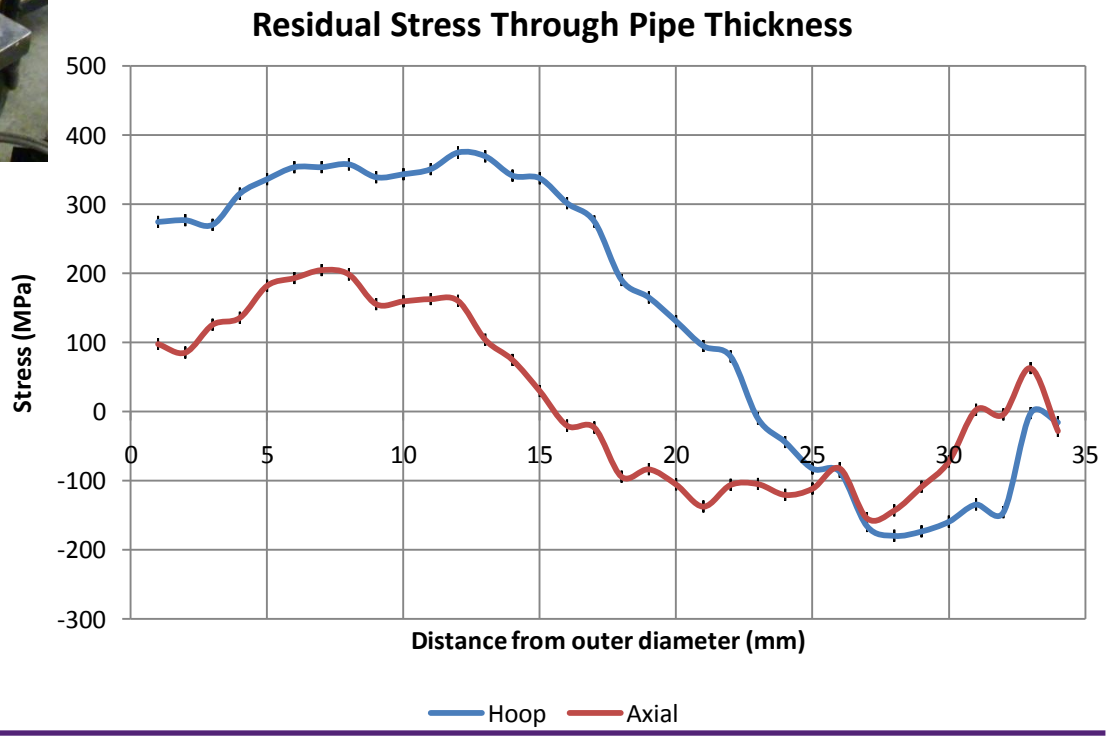
Residual stress measurements - iDHD



Residual stress measurements - iDHD

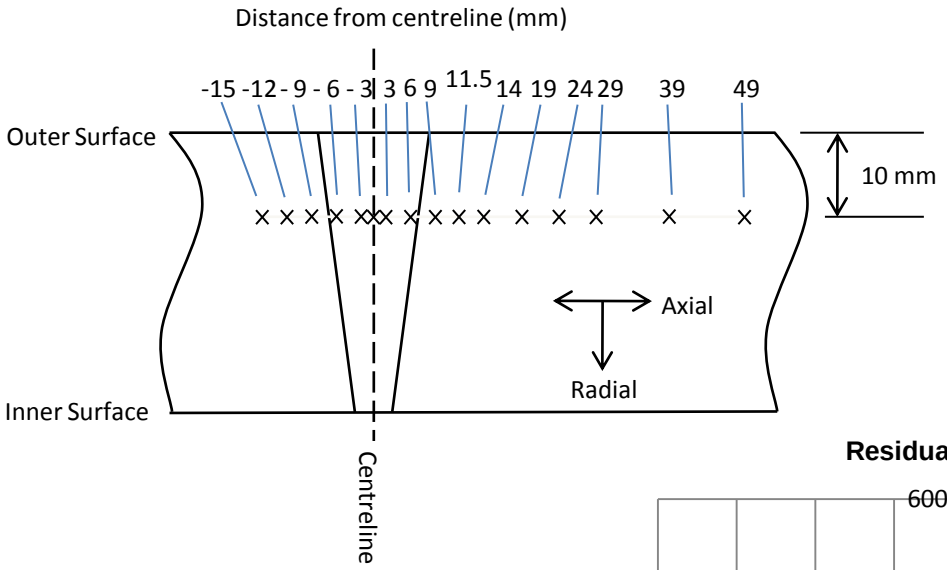




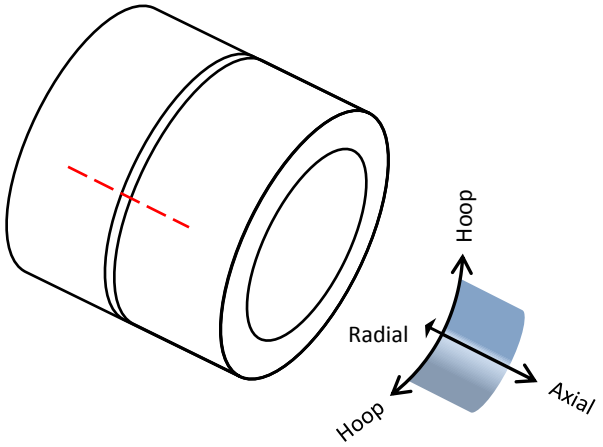


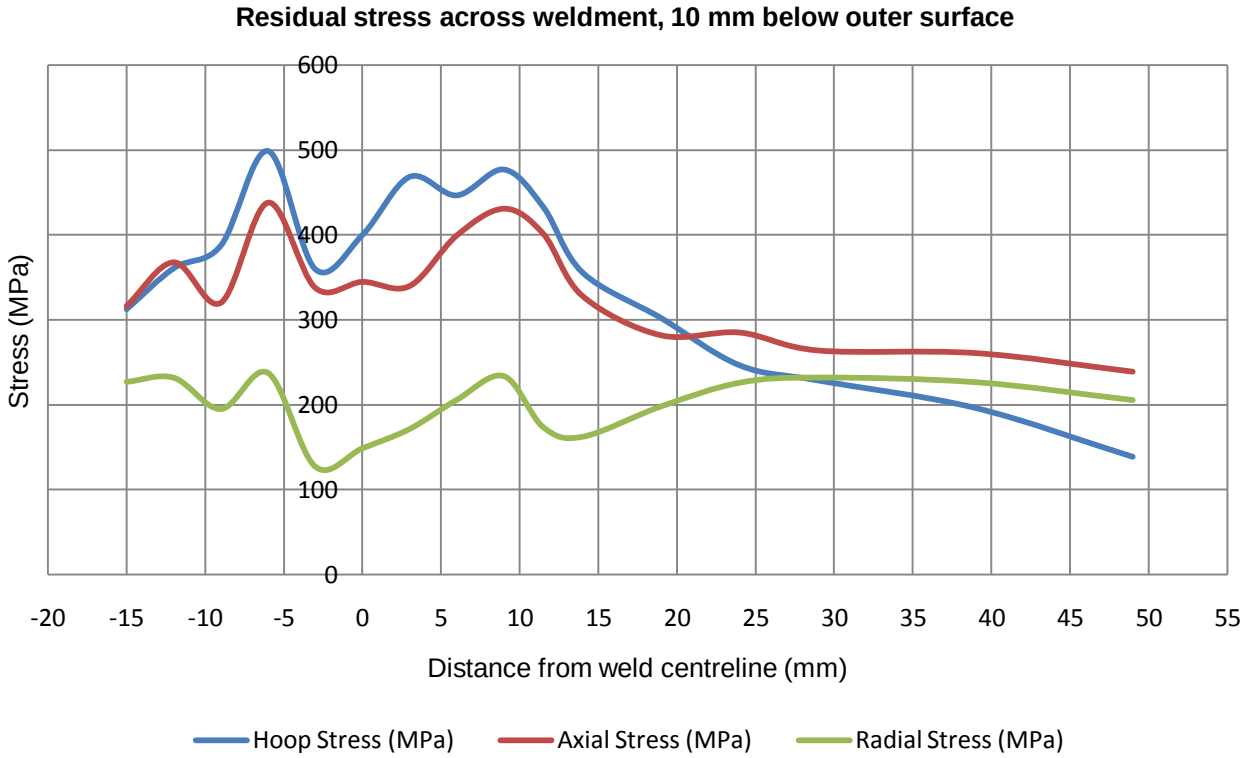
Performed at the department of Mechanical Engineering, University of Bristol

Residual stress measurements – Neutron Diffraction

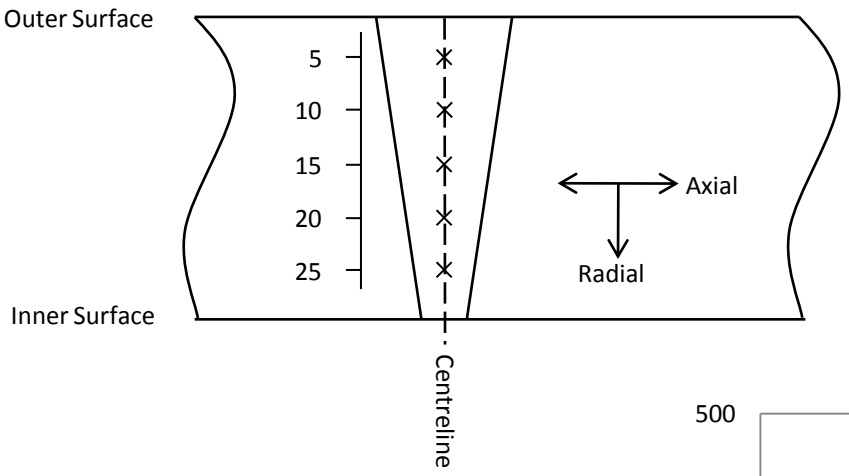


Performed on the ENGIN-X instrument, ISIS neutron source, Rutherford-Appleton Laboratories, Harwell



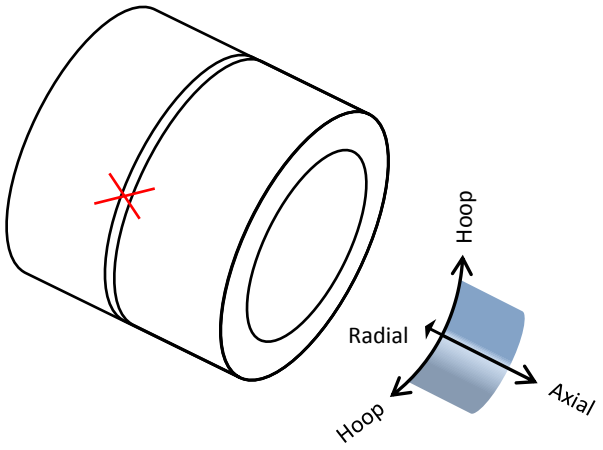


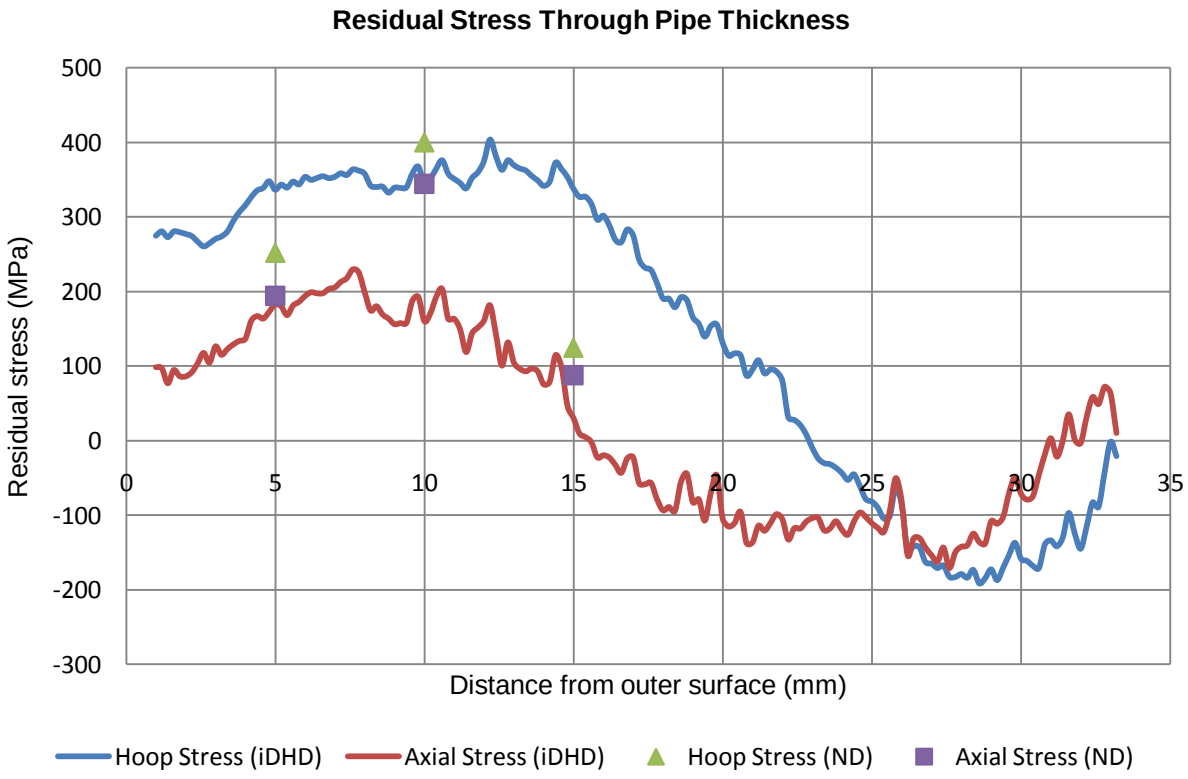
Residual stress measurements – Neutron Diffraction



Issues:

- Measurement volume – refined enough?
- Weld weave
- Diffraction comb – strain free?



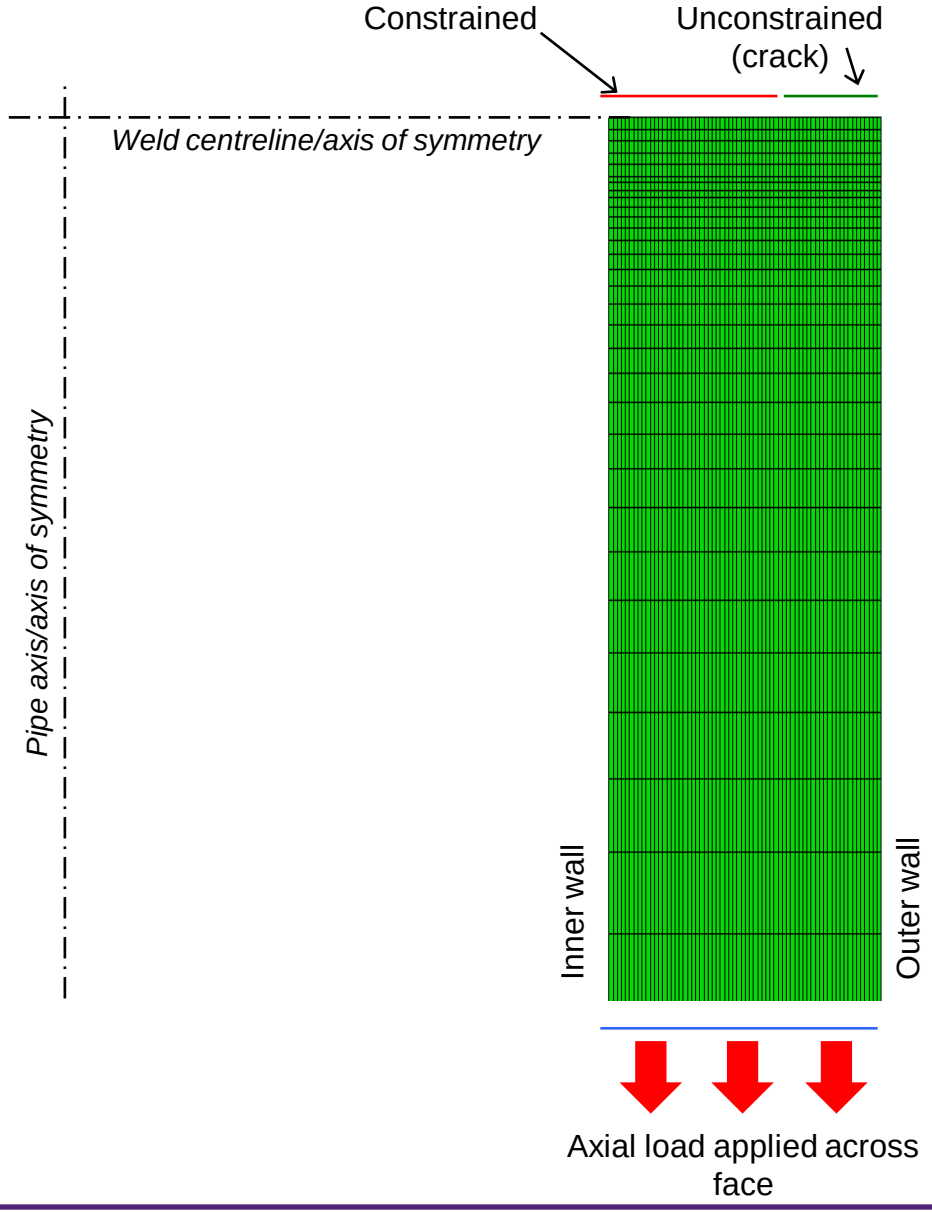


Numerical Modelling – structural test

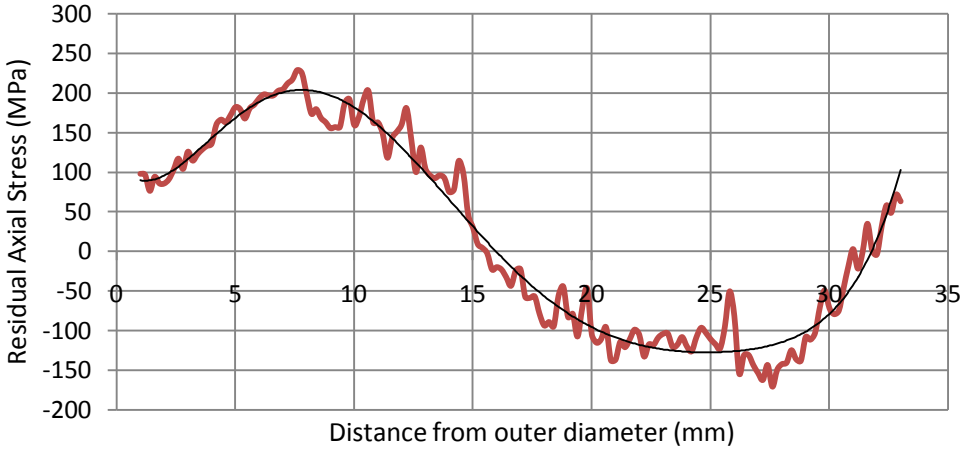
Model created using Abaqus v6.8, utilising all of the experimental data

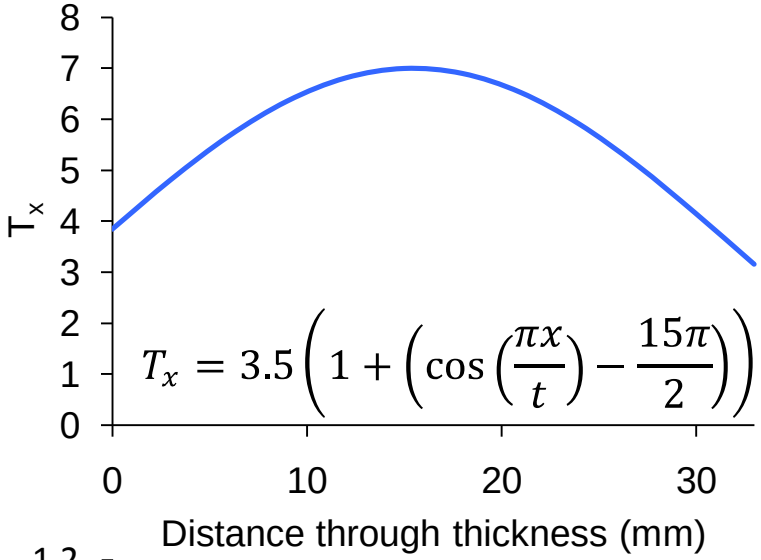
2-D axisymmetric model:

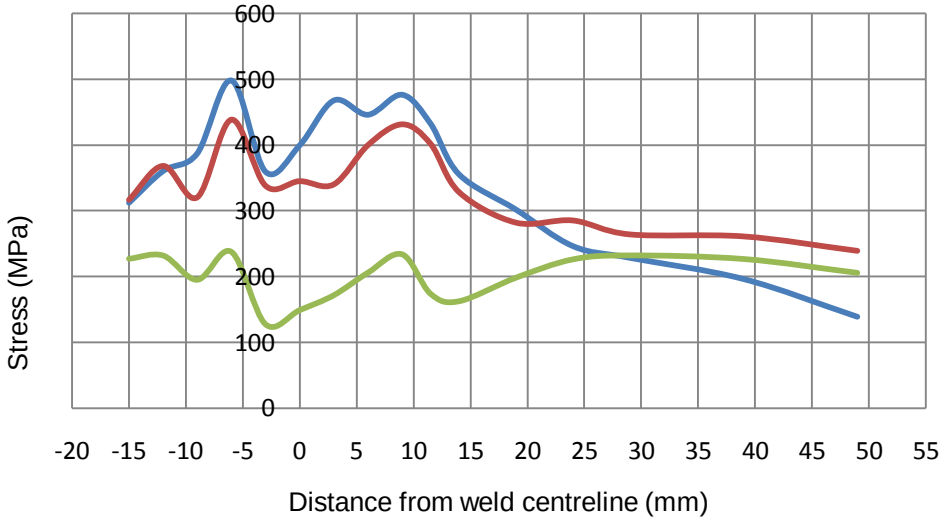
- CAX8R elements
- 0.5 mm elements along weld centreline
- Global axial load applied
- User defined subroutine developed to apply temperature distribution along weld centreline – residual stress field
- Elastic, elastic-plastic and elastic-perfectly plastic material behaviour modelled

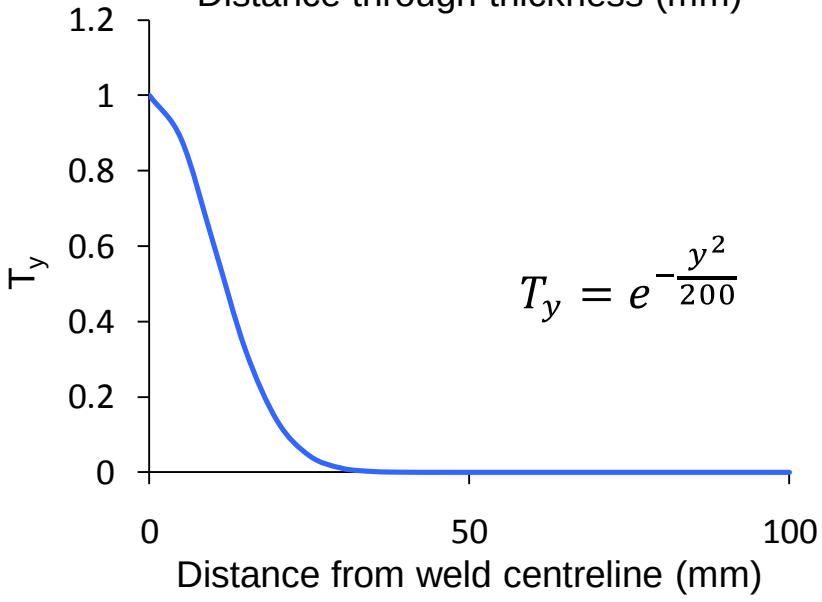


Modelling the measured residual stress field

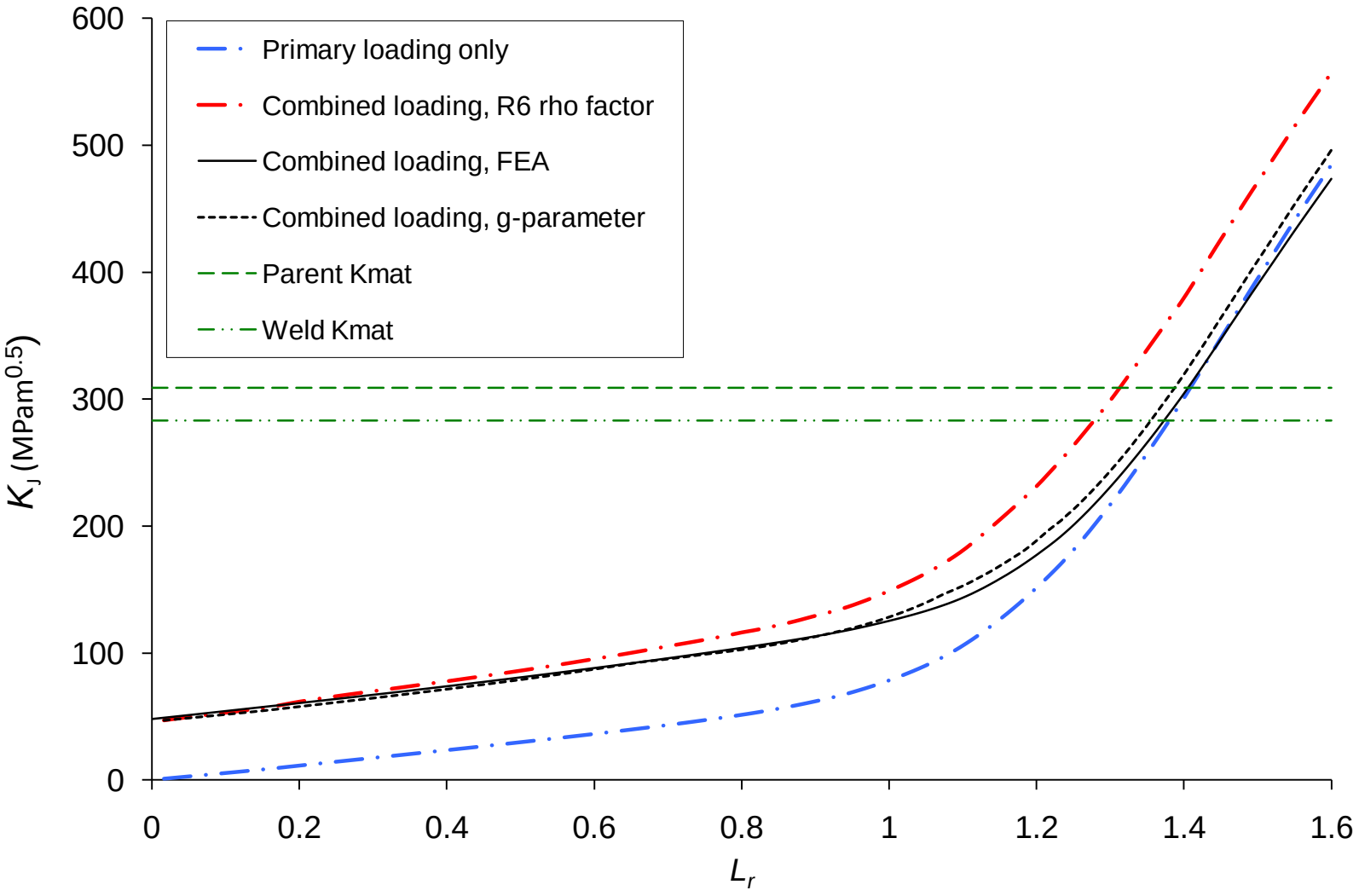








Full FE and R6 analysis for postulated 7 mm deep crack



In conclusion...

- Characterised the residual stress field across an austenitic narrow-gap girth-butt TIG weld
  - *Measured residual stresses depend on technique used*

- Established mechanical properties of parent and weld material
  - 60% overmatched
  - *Measuring fracture toughness in narrow-gap welds an issue – validity limits set out by the standards*

- Performed simulations of a full-scale structural test on the component with a residual stress present, applied to an R6 assessment
  - *Compared two different interaction parameters to predict component failure*

- *Further work: does the SEN(B) specimen orientation affect measured weld fracture toughness? How might this affect assessments of different materials?*

Any questions?