Mätning, simulering och validering av svetsegenspänningar inom ATLAS+

Daniel Mångård, Kiwa Inspecta Technology AB

Kiwa Inspecta

Trust
Quality
Progress

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Advanced Structural Integrity Assessment Tools for Safe Long Term Operation

Specifically this project will focus on developing:

- innovative quantitative methodologies to transfer laboratory material properties to assess the structural integrity of large piping components,
- an enhanced treatment of weld residual stresses when subjected to long term operation,
- advanced simulation tools based on fracture mechanics methods using physically based mechanistic models,
- improved engineering methods to assess components under long term operation taking into account specific operational demands,
- integrated probabilistic assessment methods to reveal uncertainties and justify safety margins.

European Commission

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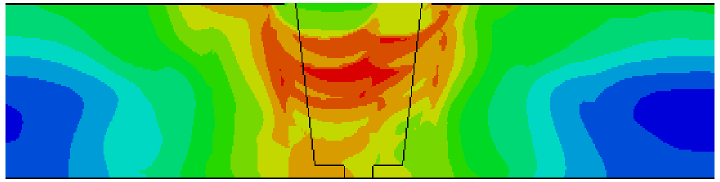
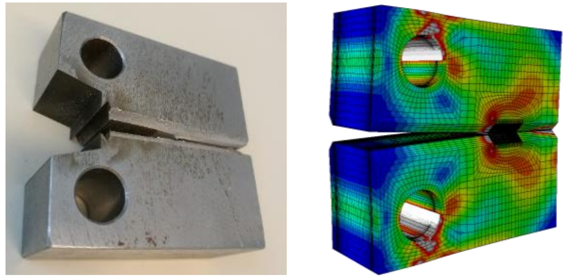
Overview of work packages

The work within ATLAS+ is organized into the following Work Packages:

- WP 1: Design and execution of full scale experiments to validate models
- **WP 2: Simulation and assessment of weld residual stresses**
- WP 3: Advanced integrity assessment for justification of safe LTO
- WP 4: Assessment of safety margin using probabilistic approaches
- WP 5: Training and dissemination
- WP 6: Project management


WP 2: Simulation and assessment of residual stress

- **Structure of sub-work packages:**
  - **WP 2.1: Weld residual stress simulation and validation**
  - WP 2.2: Development of residual stress profiles
  - WP 2.3: Effect of ageing and operational conditions on residual stress
  - WP 2.4: Effect of residual stresses on fracture

- **Objectives:**
  - Extend, improve and validate techniques for weld residual stress simulation.
  - Manufacture, characterize and perform residual stress measurements on targeted weldment mock-ups to validate simulation techniques and provide input to structural integrity assessment procedures.
  - Develop improved descriptions of residual stress for common weld configurations.
  - Examine the effects of ageing and operational conditions on residual stress profiles.
  - Explore routes to include residual stresses in fracture assessment methods.

WP 2.1: Weld residual stress simulation and validation

- Reliable prediction remains difficult, particularly in complex 3D structures such as weld repairs, or in structures with large welding deformations such as thin-walled pipes.
- Need to consider the impact of 2D/3D idealization methods and 3D perturbation effects associated with bead start/stop.

- **Structure of sub-work packages:**
  - WP 2.1.1: Provision of weld mock-ups for development and validation of simulation techniques.
  - WP 2.1.2: Mock-up characterisation and residual stress measurements.
  - WP 2.1.3: Materials characterisation and modelling for welding.
  - WP 2.1.4: Weld residual stress simulation.

- **Objectives:**
  - Provision of appropriately characterised weld mock-ups for development, validation and optimisation of simulation techniques.
  - Mock-up characterisation and diverse residual stress measurements.
  - Validated simulation techniques.

WP 2.1.1: Provision of weld mock-ups 1(3)

- Manufacture of three designs of plain pipe girth weld [austenitic steel, AISI 316L]:
  - Two off, narrow-groove (NG-GTAW) thick-walled
  - Two off, thin-walled – High Heat Input (Hi-HI)
  - Two off, thin-walled – Low Heat Input (Lo-HI)

MANCHESTER 1824
The University of Manchester
Dalton Nuclear Institute

➢ Aim: to fill in gaps in the current population of pipe girth weld mock-ups used to train artificial neural networks (ANN) to predict residual stresses.

- Manufacture of two overlay welds [low-alloy steel, P265GH]:
  - One pipe with a fully circumferential overlay repair
  - One pipe with a patch repair, extending over 120° of the circumference

EDF ENERGY

➢ Aim: to investigate the performance of weld overlay repairs.

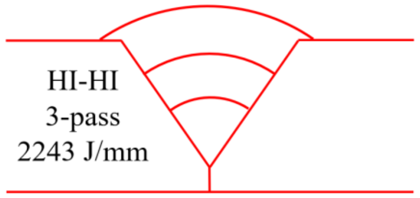
- Manufacture one plain pipe girth weld [AISI 316L]:
  - NG-GTAW - aged for 3000h at 400°C

cea

➢ Aim: to investigate the impact of thermal ageing on residual stress development in service.

WP 2.1.1: Provision of weld mock-ups 2(3)

2 x



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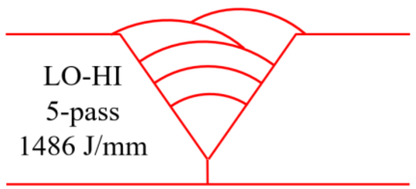
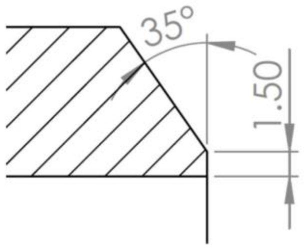


Wall thickness = 9mm
Ro/t = 13.9
Weld process = conventional GTAW
Material = AISI 316L



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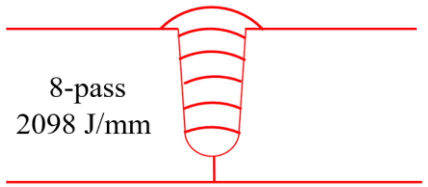
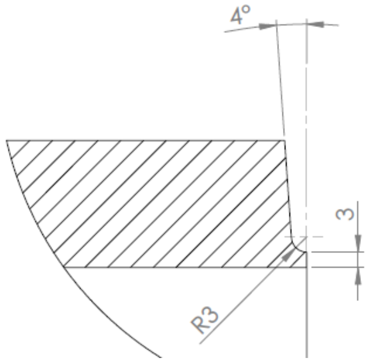
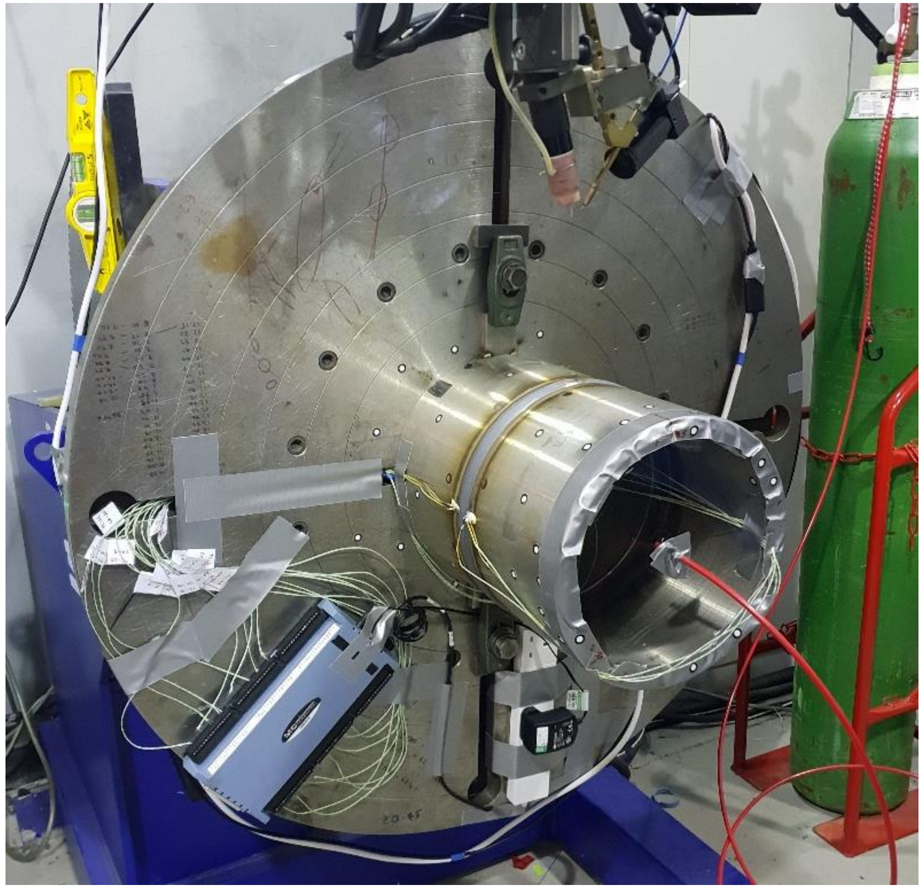


25mm NG-GTAW mock-up
Length = 350mm
Outer diameter = 250mm
Wall thickness = 25mm
Ro/t = 5
Weld process = NG-GTAW
Material = AISI 316L





AT-W03 (Hi-HI)

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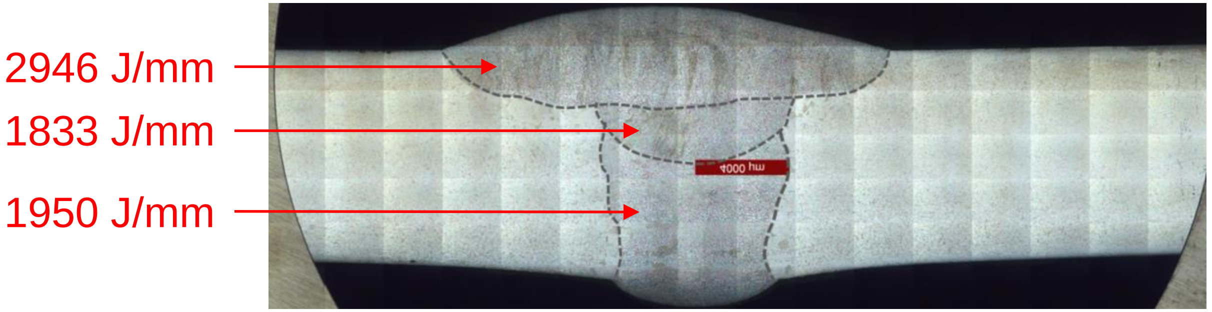
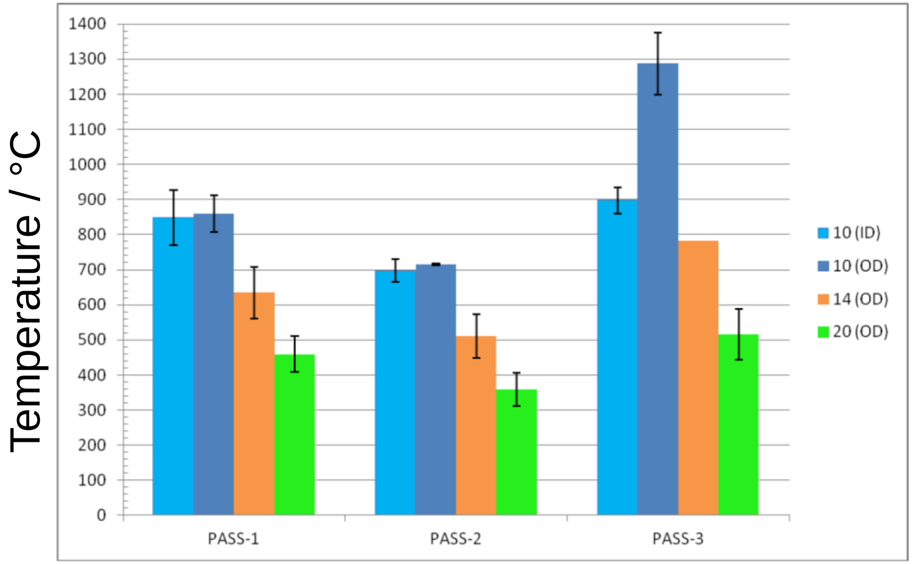
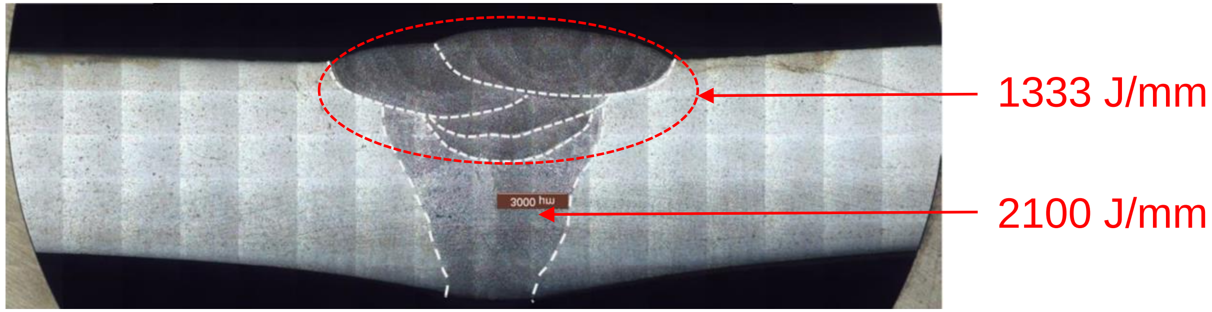
WP 2.1.1: Provision of weld mock-ups 3(3)

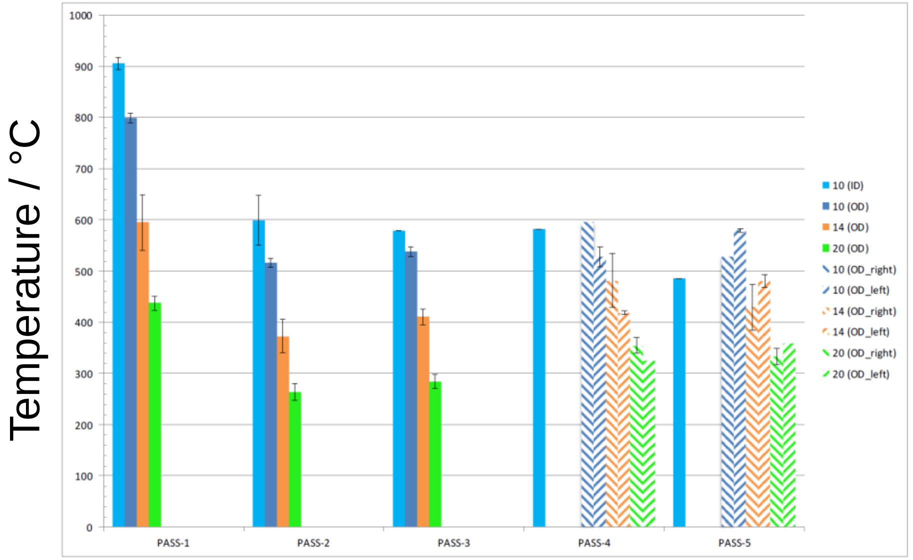
AT-W03 (Hi-HI)





AT-W01 (Lo-HI)





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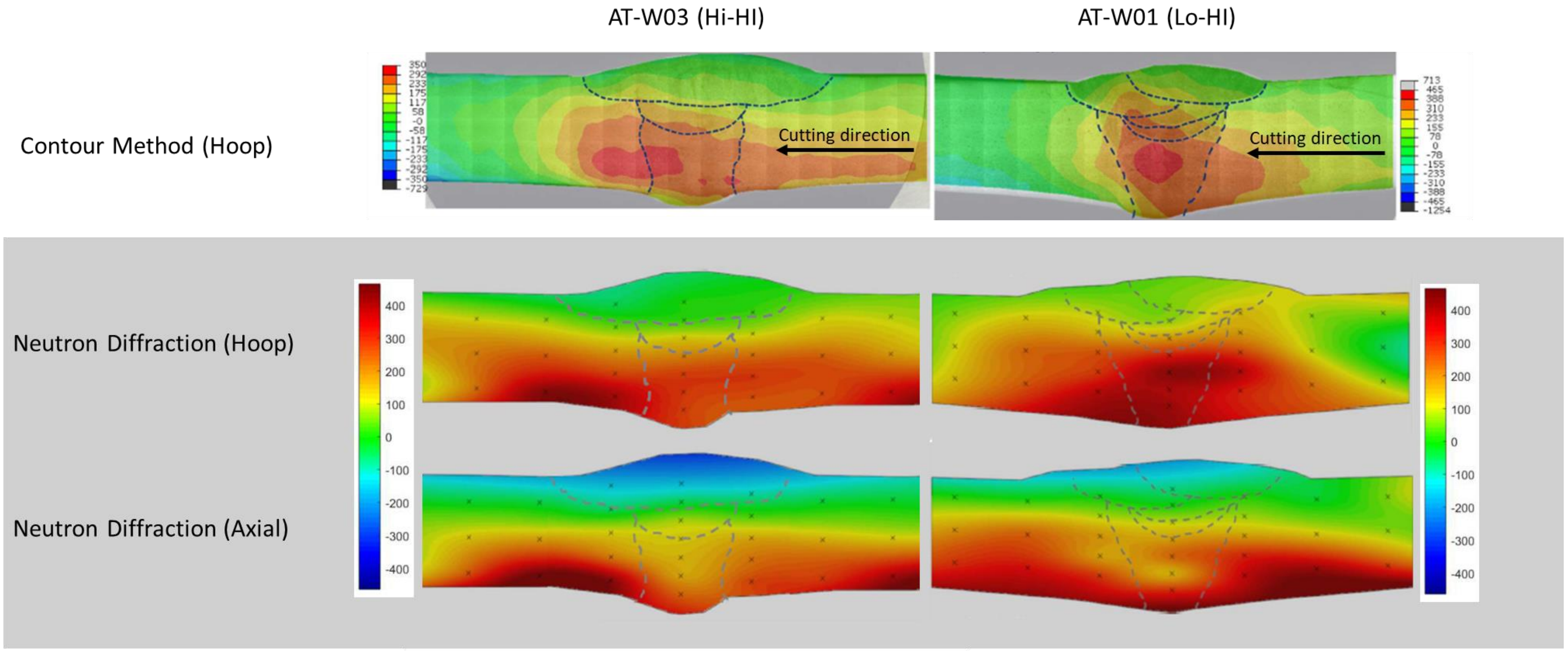
WP 2.1.2: Mock-up characterisation and residual stress measurements



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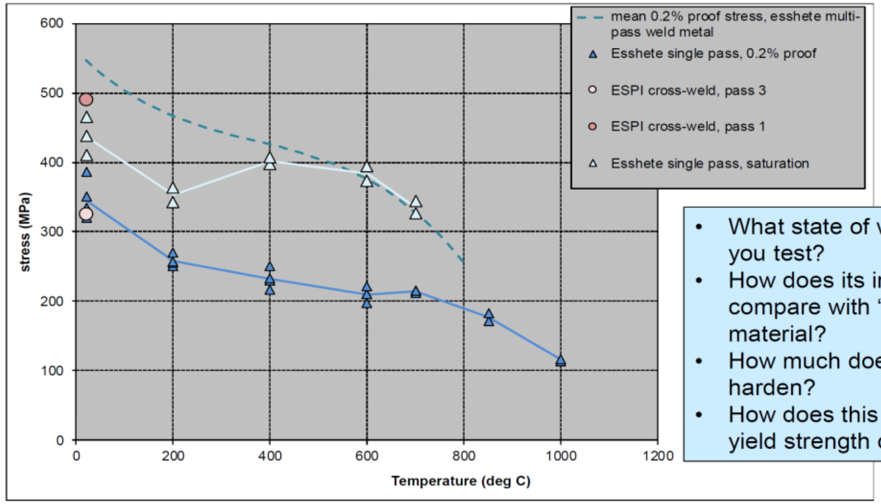
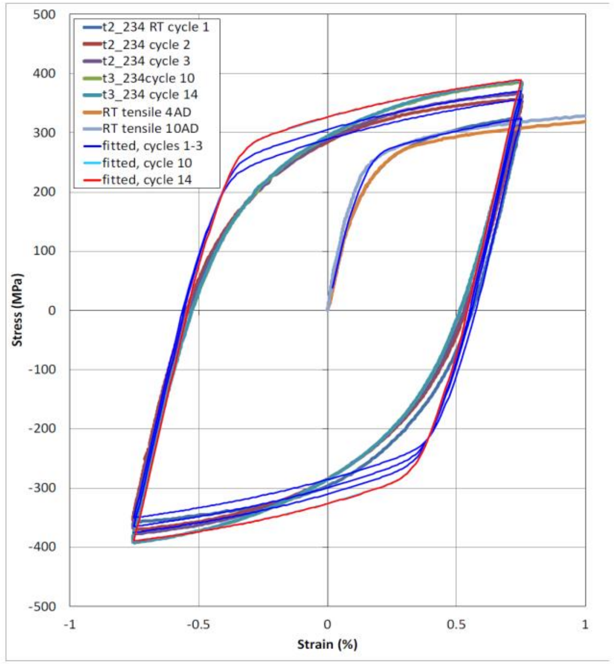
WP 2.1.3: Materials characterisation and modelling for welding



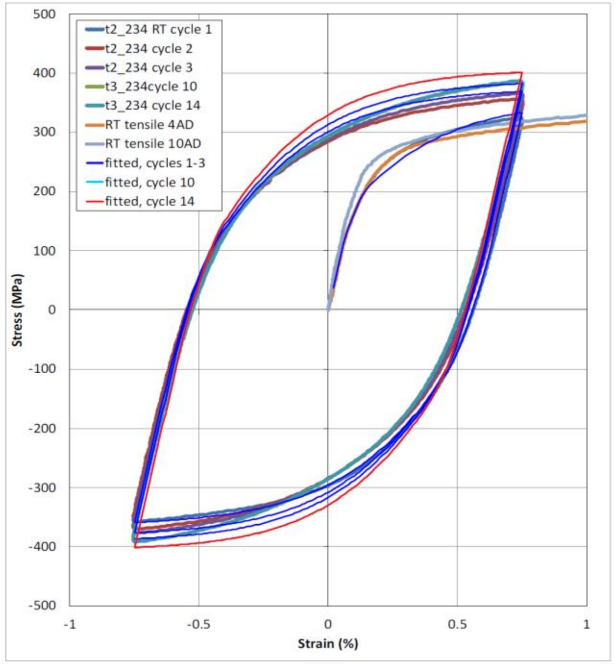
- What state of weld metal should you test?
- How does its initial yield strength compare with "as-deposited" material?
- How much does it cyclically harden?
- How does this compare with the yield strength of real welds?

Testing of weld metal, and extraction of material parameters (Chaboche model), must be performed with care.

Kinematic parameters fitted to monotonic response



Kinematic parameters fitted to cycle 2 re-load



No materials testing is planned in WP 2.

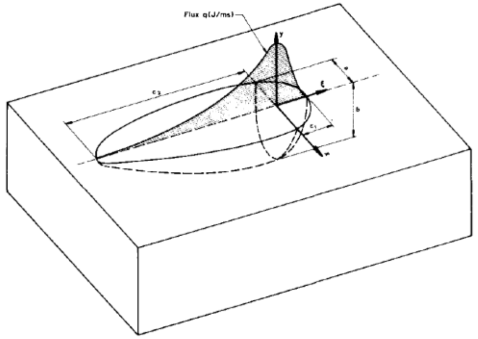
The plan is to use existing data generated as part of the work of the NeT* network projects (TG1 and TG4).

* Neutron Techniques Standardisation for Structural Integrity.

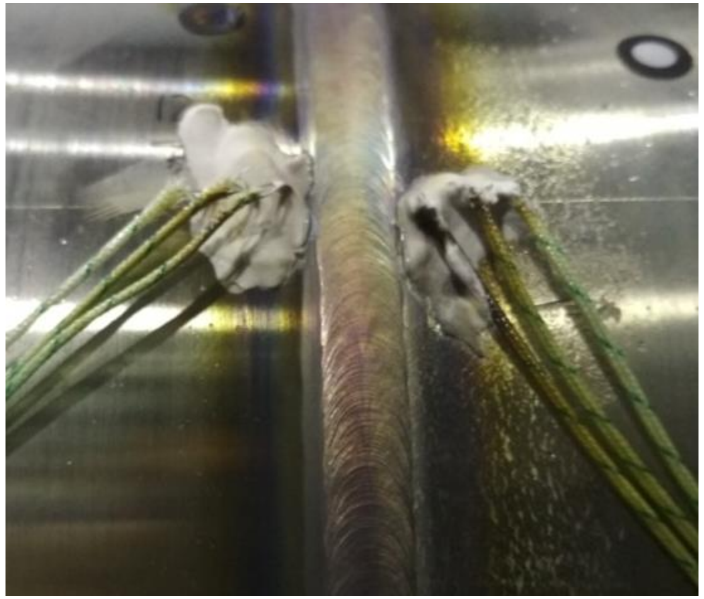
WP 2.1.4: Weld residual stress simulation 1(4)

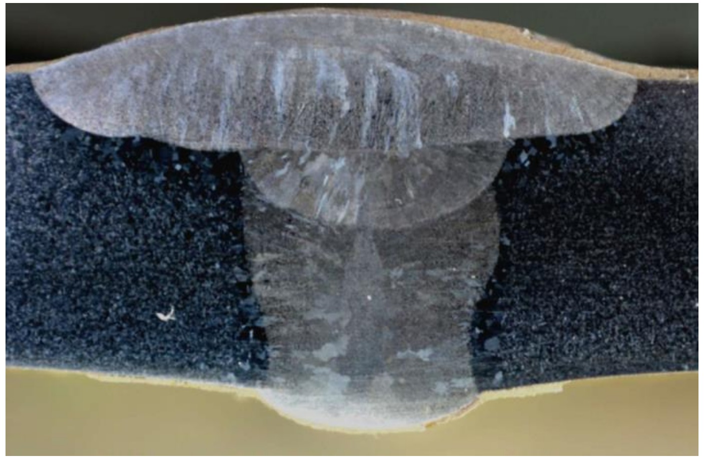
- **Simulation accuracy targets:**
  - The predicted cross-sectional area of fused weld/parent metal at mid-length of each of the beads shall be within ±20% of the mean measured fused area.
  - The predicted increases in temperature, $\Delta\theta = (\theta_{\text{peak}} - \theta_0)$ should agree with the mean measured increases, $\Delta\theta_{\text{mean}}$ to within ±10%.

- **Modelling strategy:**
  - 2D axi-symmetric analyses.
  - Sequencial thermal and mechanical analyses using Abaqus.
  - Modeling a suitable moving heat source to reproduce
    - welding parameters and assumed welding efficiency,
    - pass-by-pass response from far-field and near-field thermocouples,
    - transverse fusion boundary profiles.
  - Thermal and mechanical boundary conditions.
  - Mixed hardening mechanical constitutive modelling.

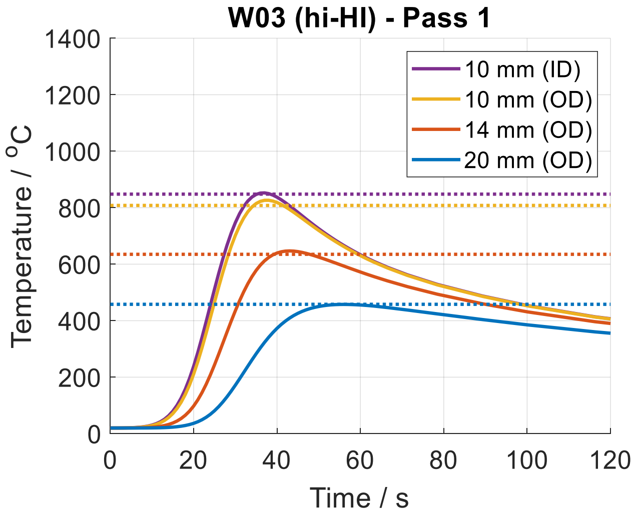


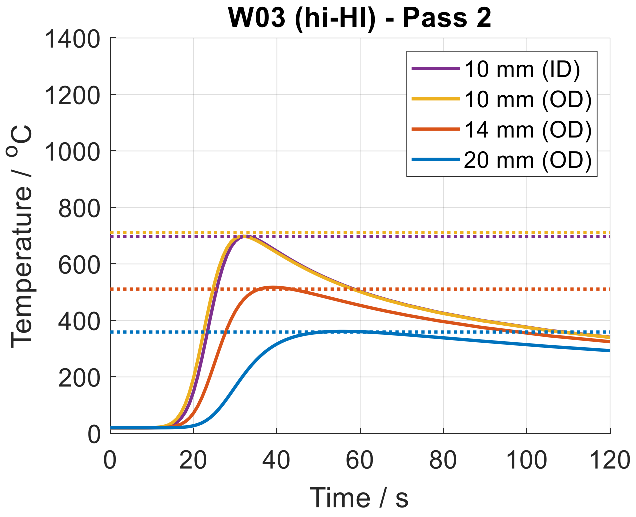
$$q(x, y, \xi) = \frac{6\sqrt{3}Q}{abc\pi\sqrt{\pi}} e^{-3x^2/a^2} e^{-3y^2/b^2} e^{-3\xi^2/c^2}$$

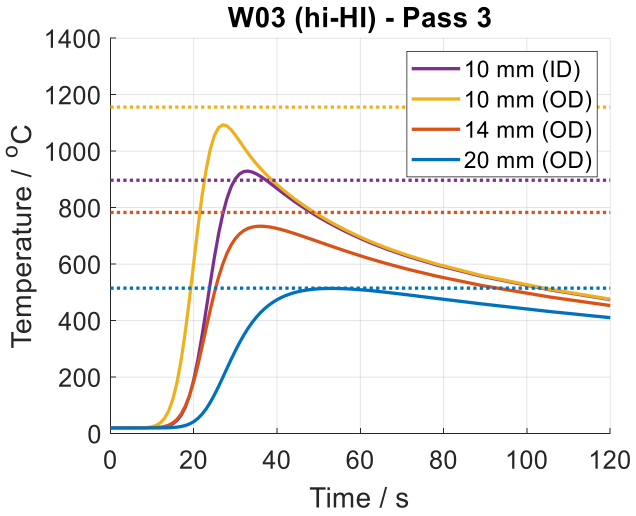


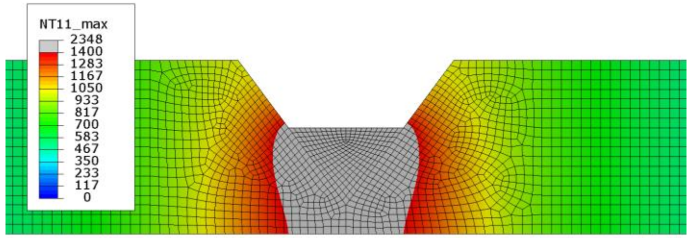


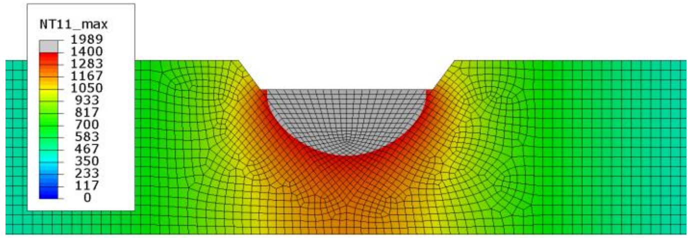
WP 2.1.4: Weld residual stress simulation 2(4)

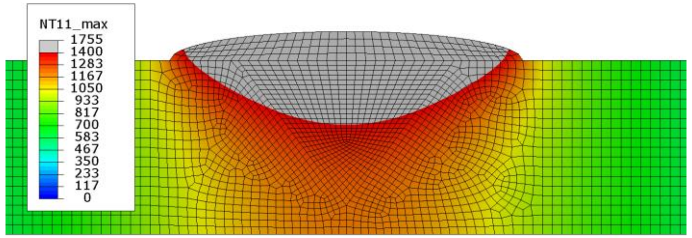


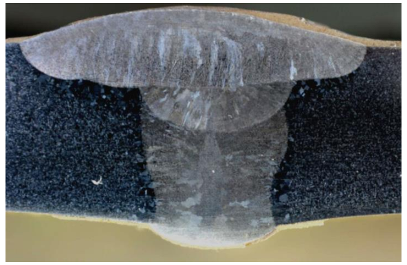








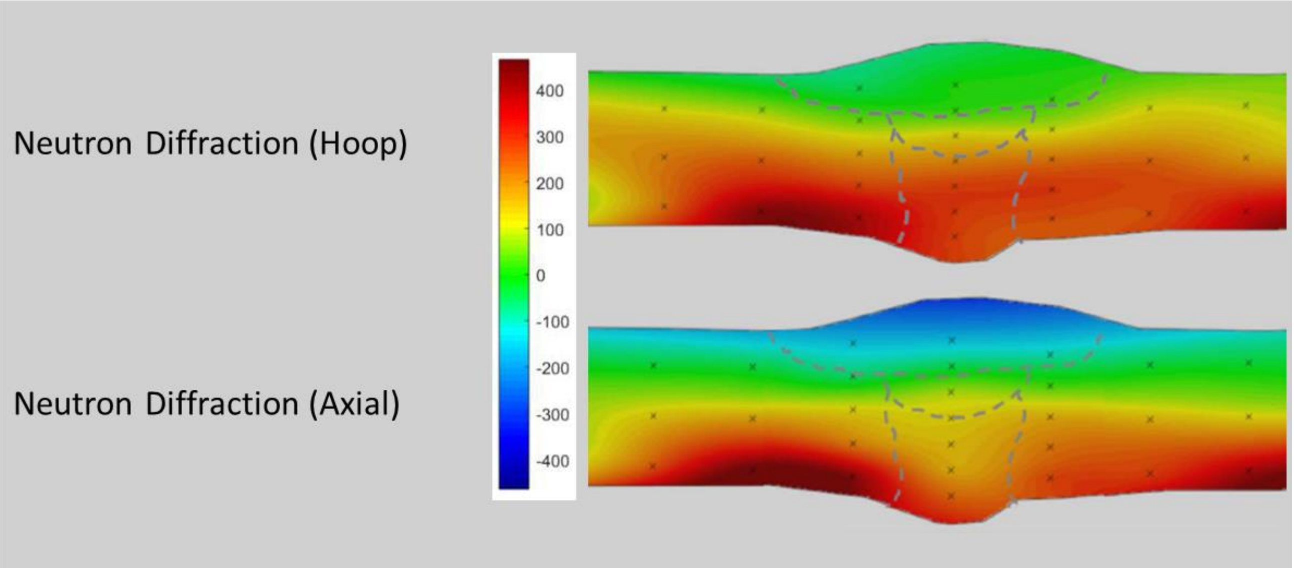




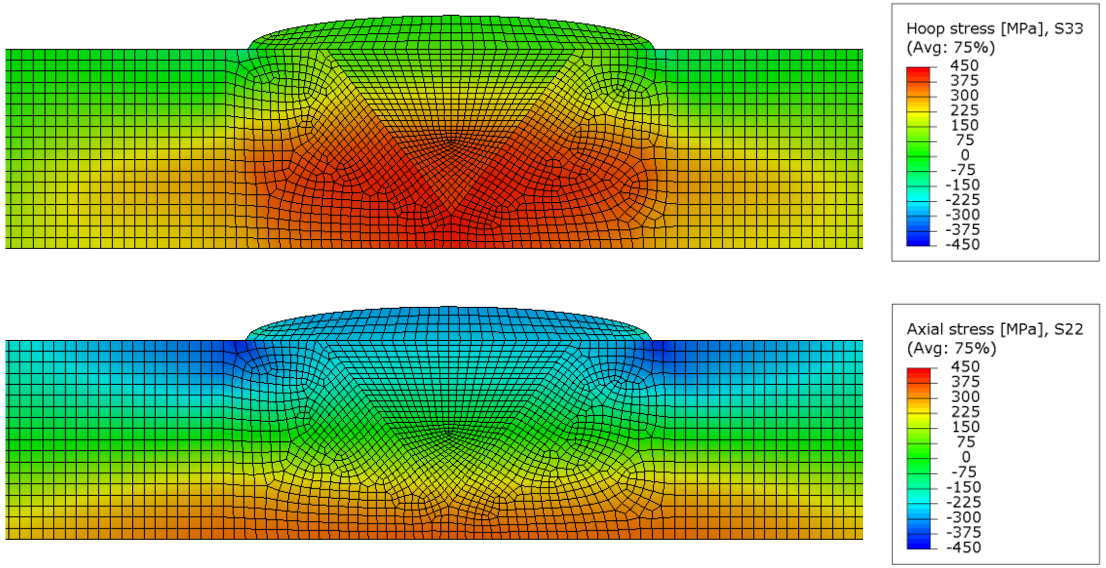
The predicted temperature increase agree with the mean measured increases to within ±10%.
Reproduction of transverse fusion boundary profiles difficult due to 2D axisymmetric idealization.

WP 2.1.4: Weld residual stress simulation 3(4)

AT-W03 (Hi-HI)



Work in progress



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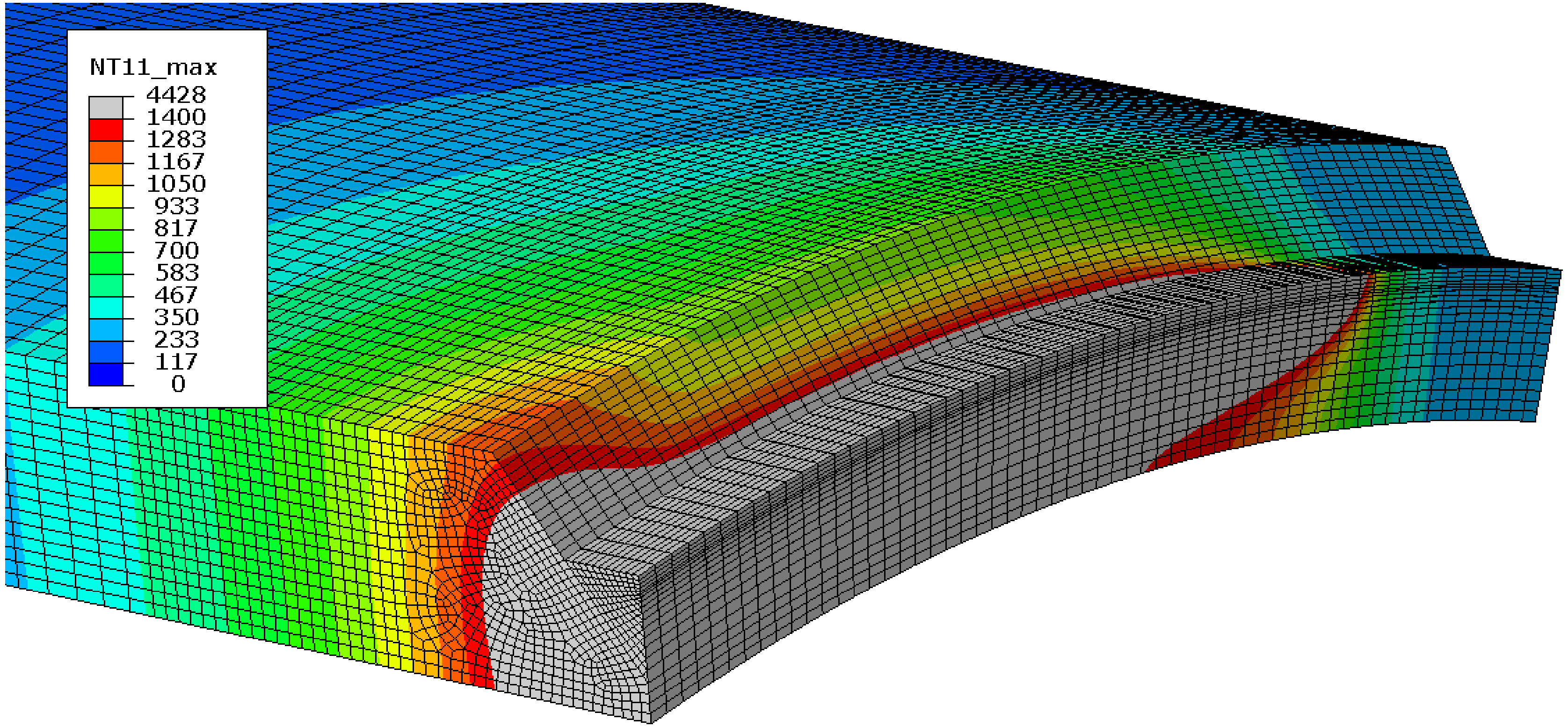
WP 2.1.4: Weld residual stress simulation 4(4)



Status

- WP 2.1 involves an ambitious mockup and residual stress measurement program:
  - Multi-cut Contour, Neutron diffraction and iDHD/DHD
  - Some measurements have been completed, and more will follow.
- Weld residual stress simulation work is ongoing:
  - The simulation protocol for the thin-walled AISI 316L pipes is complete.
    UoM and KIWA currently perform 2D axi-symmetric simulations (and 3D simulations of one pipe later).
  - The simulation protocol for the thick-walled narrow-gap AISI 316L pipes will follow.
    UoM and KIWA will perform 2D axi-symmetric simulations.
  - BZN and VTT establish simulation protocol and perform simulations for safe end welds.
  - EDF establish simulation protocol and perform simulations for ferritic overlay welds.

Tack!