Measurements and Finite Element Predictions of Residual Stresses in Girth-Welded Clad pipe

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Introduction

- **Work funded by Industrial Members of TWI, as part of the Core Research Programme.**
- **Objectives:**
  - **Measurement of residual stresses in clad pipe girth welds using various measurement techniques**
  - **Development and validation of FEA models with ABAQUS and SYSWELD for simulation of welding residual stresses in clad pipe girth welds.**
  - **Assessment of the effects of heat input, material hardening models, yield stress, weld start/stop on welding residual stresses.**
  - **Provision of recommendation for the consideration of residual stresses in engineering critical assessments of clad pipe girth welds.**

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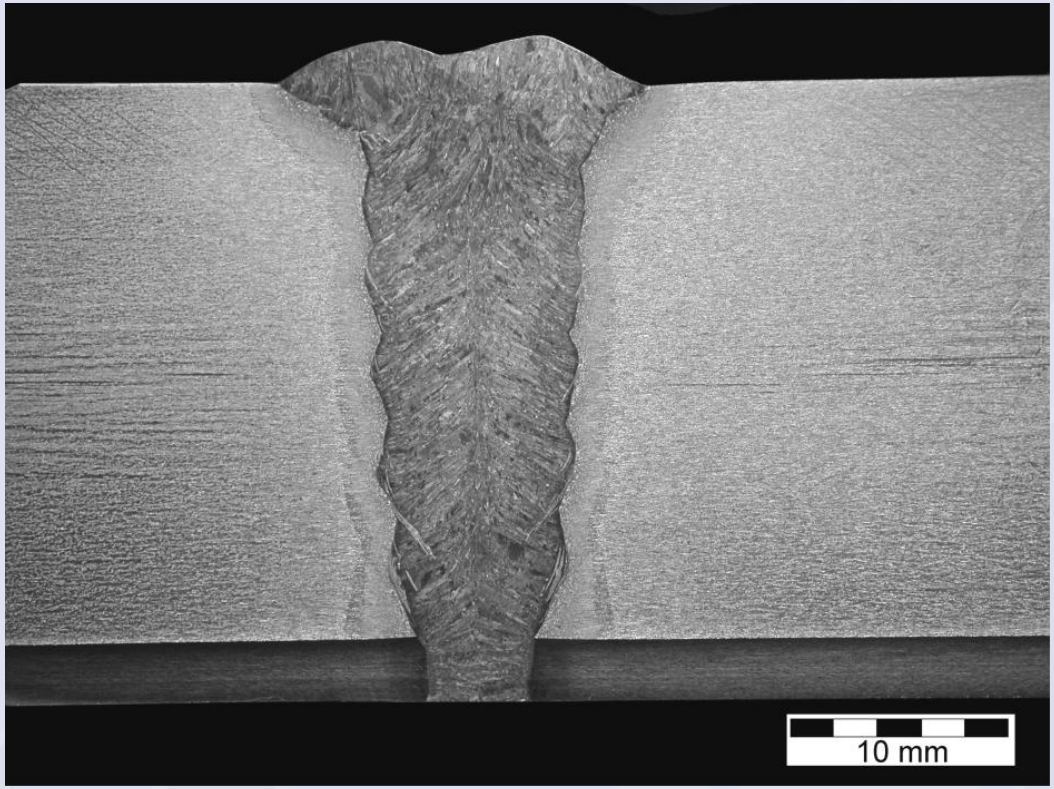
Outline

- Experiments
  - Welding
  - Tensile tests, hardness tests
  - Temperature measurements
  - Residual stress measurements: Centre hole drilling (CHD), X-ray diff (XRD), Block removal, splitting and layering (BRSL)
- Models
  - Sysweld, Abaqus
  - Kinematic and isotropic hardening
- Results and comparison
- Conclusions

Welding

- X65 pipe clad with 316L
- 609.6mm OD and 27.9mm wt (inc. 2.5mm cladding)
- Alloy 2209 filler
- Root pass: auto GMAW
- 8 further passes: auto PGMAW



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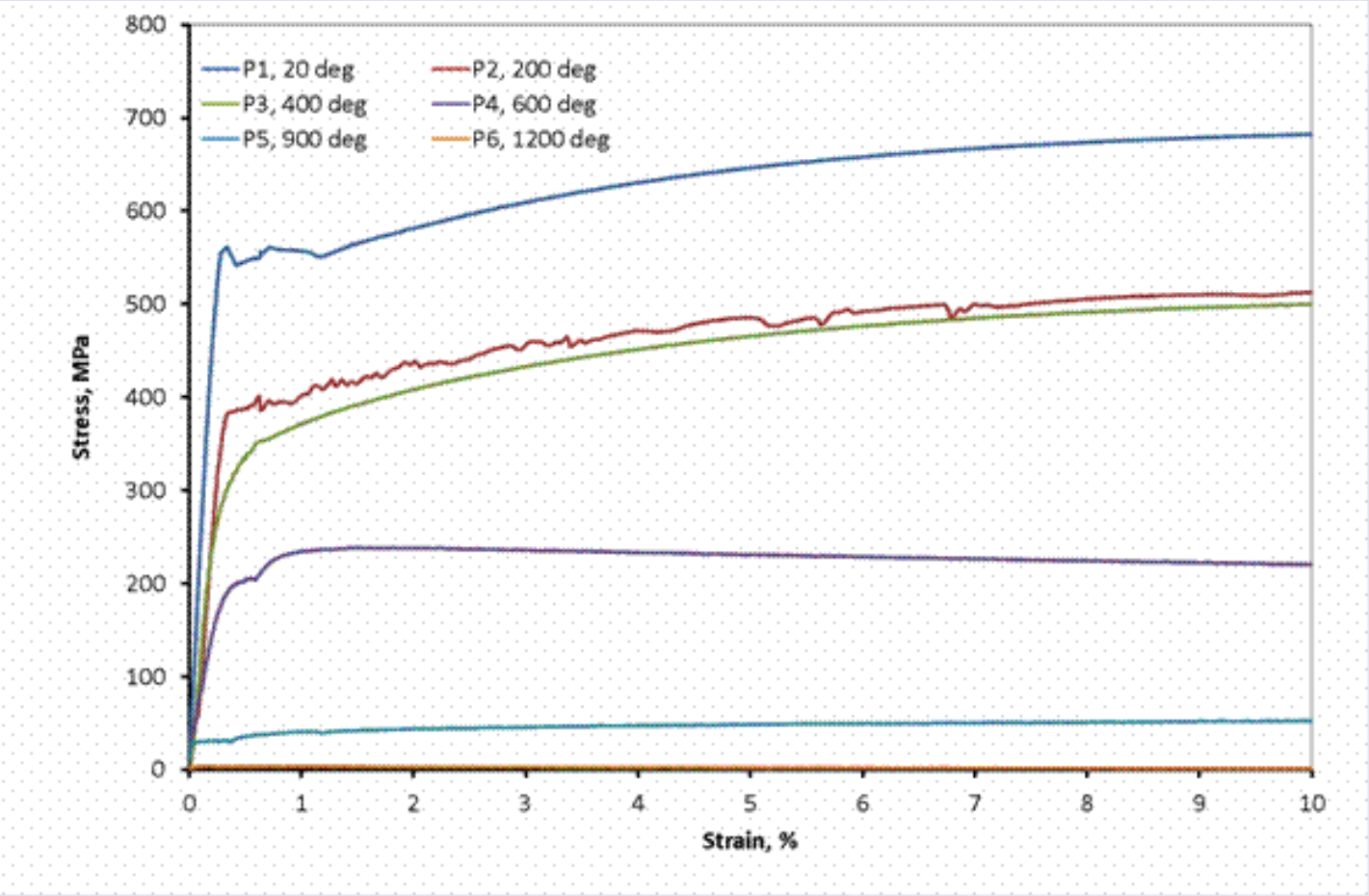
Tensile Tests - 1

- Stress-strain curves for X65, modelled as linear



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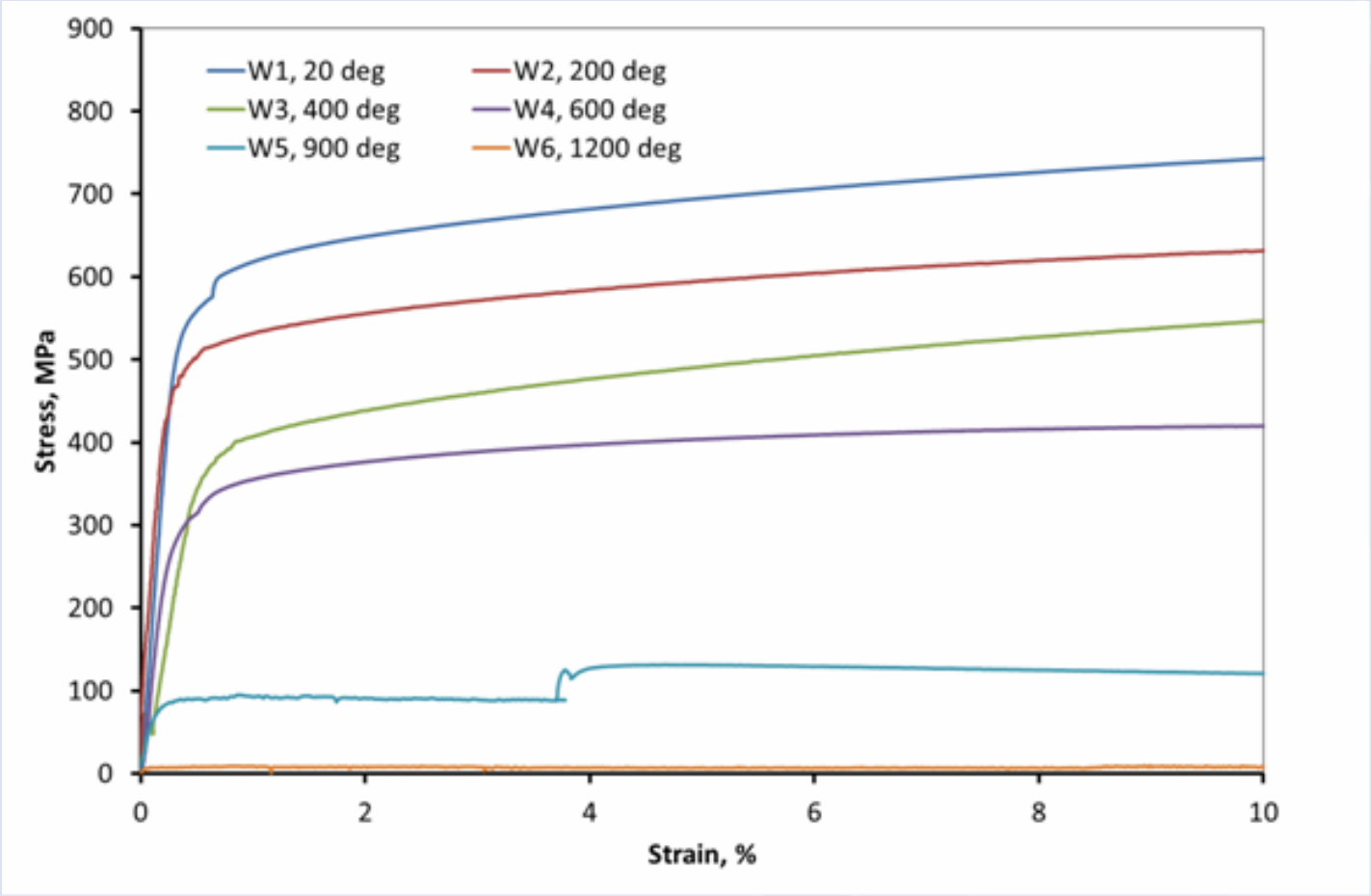
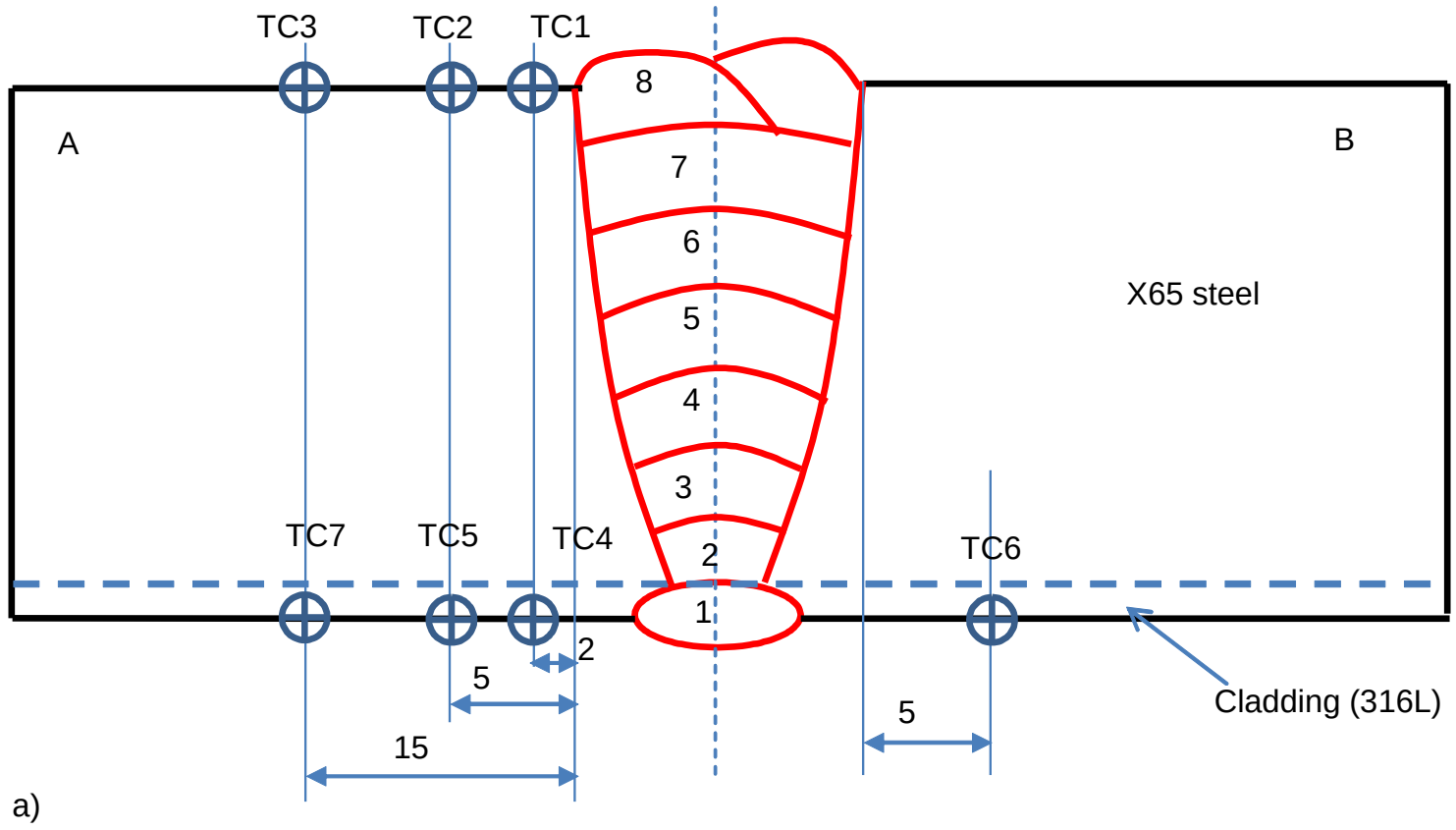
Tensile Test - 2

- Stress-strain curves for alloy 2209, modelled as linear



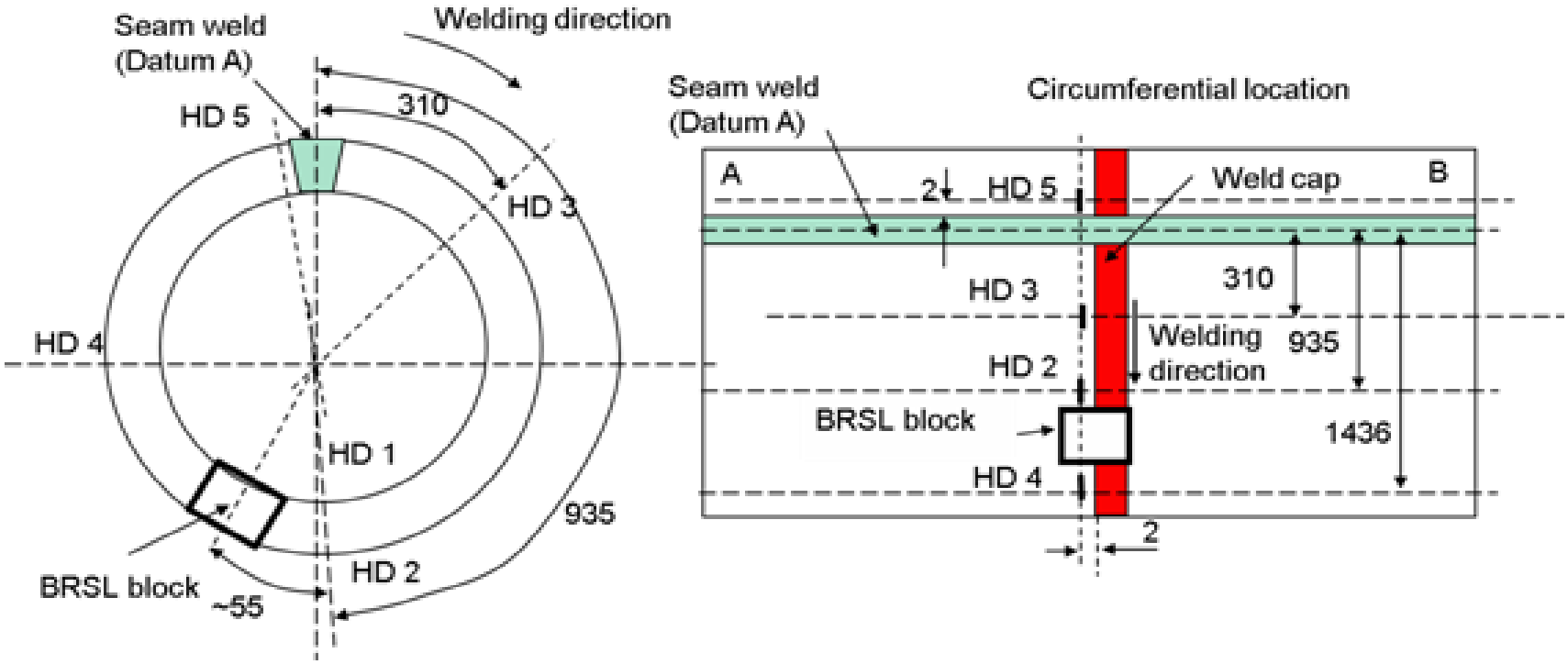
Temperature Measurements

- TCs opposite seam weld and start-stop locations



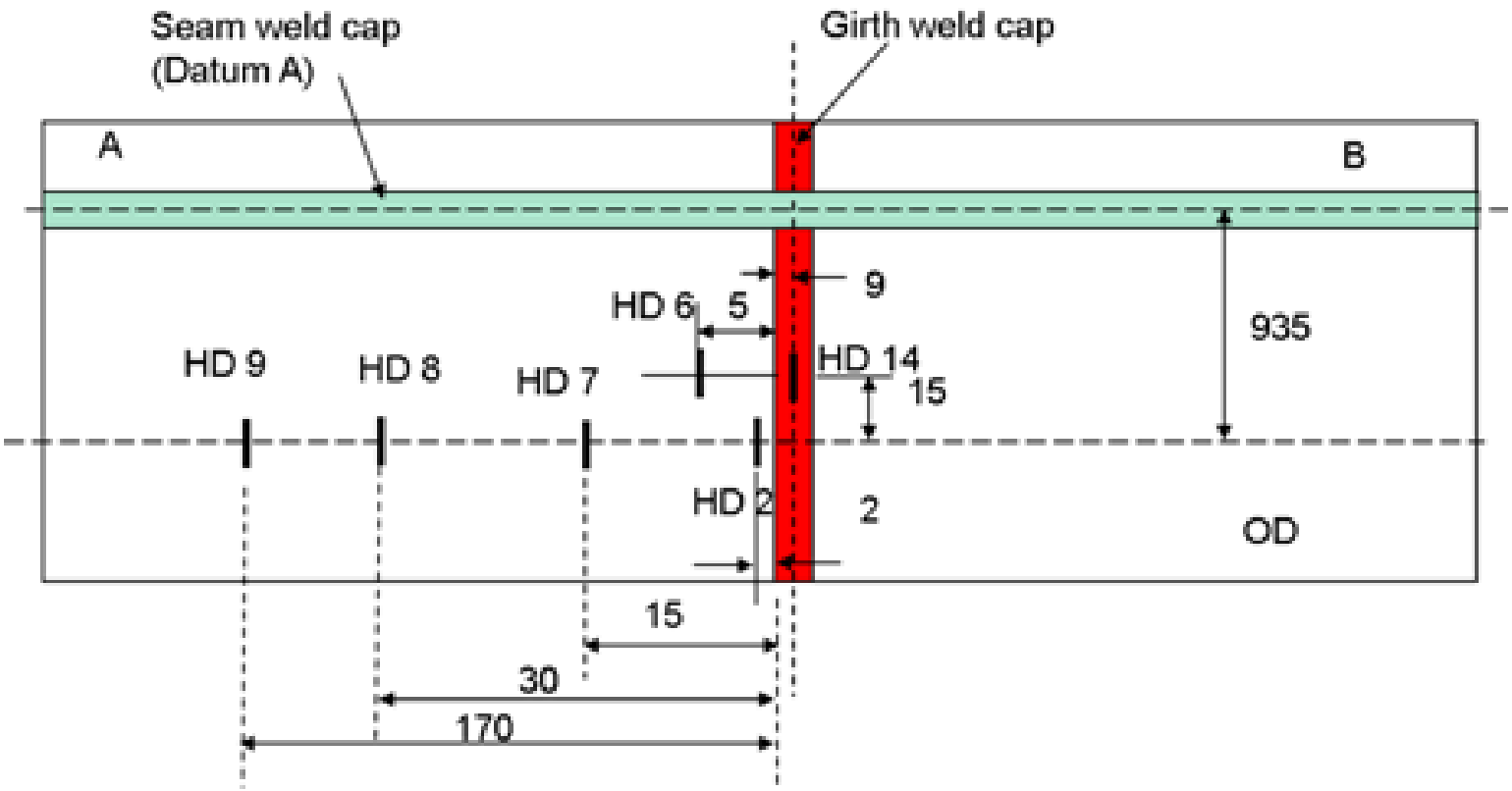
Residual Stress Measurements - 1

- XRD, CHD and BRSL



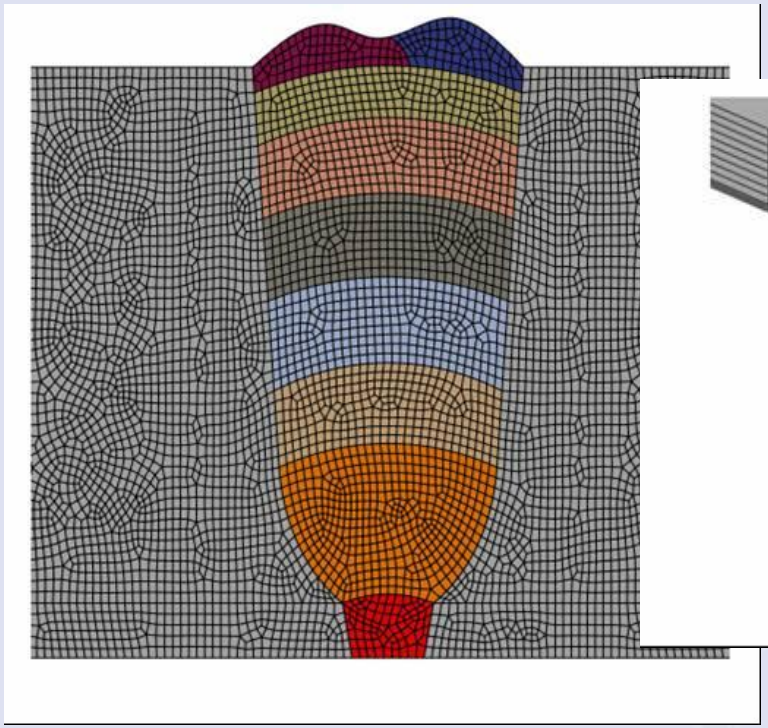
Residual Stress Measurements - 2

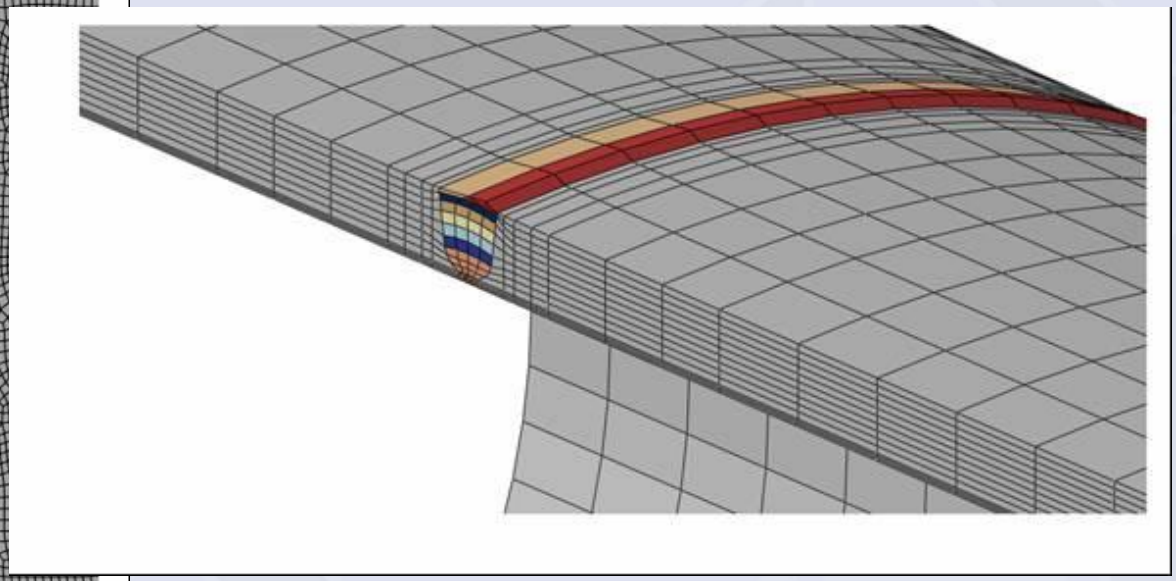
- RS measured by CHD at inner and outer surface



Models - Abaqus

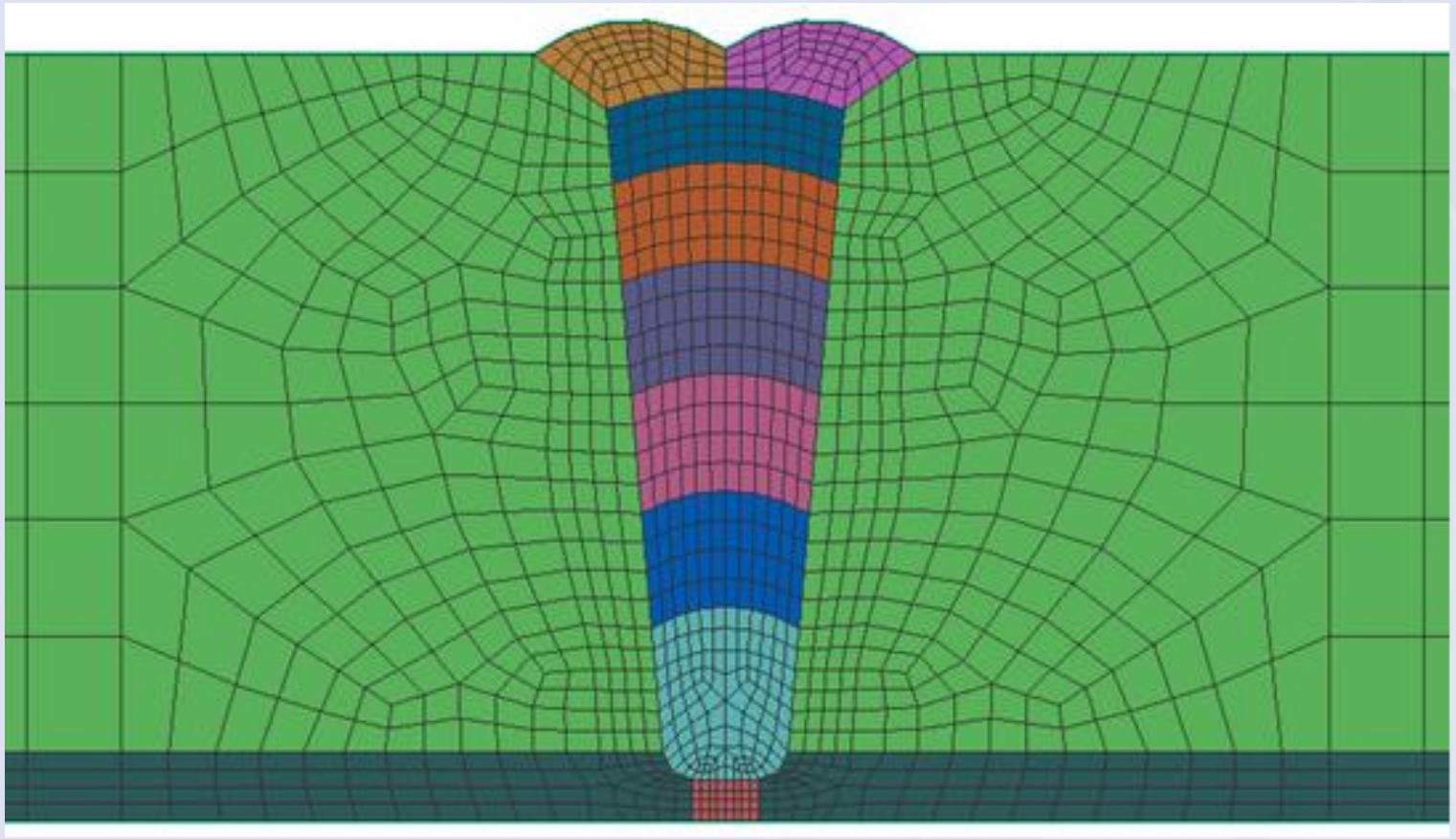
- 2D axi-symmetric and 3D models





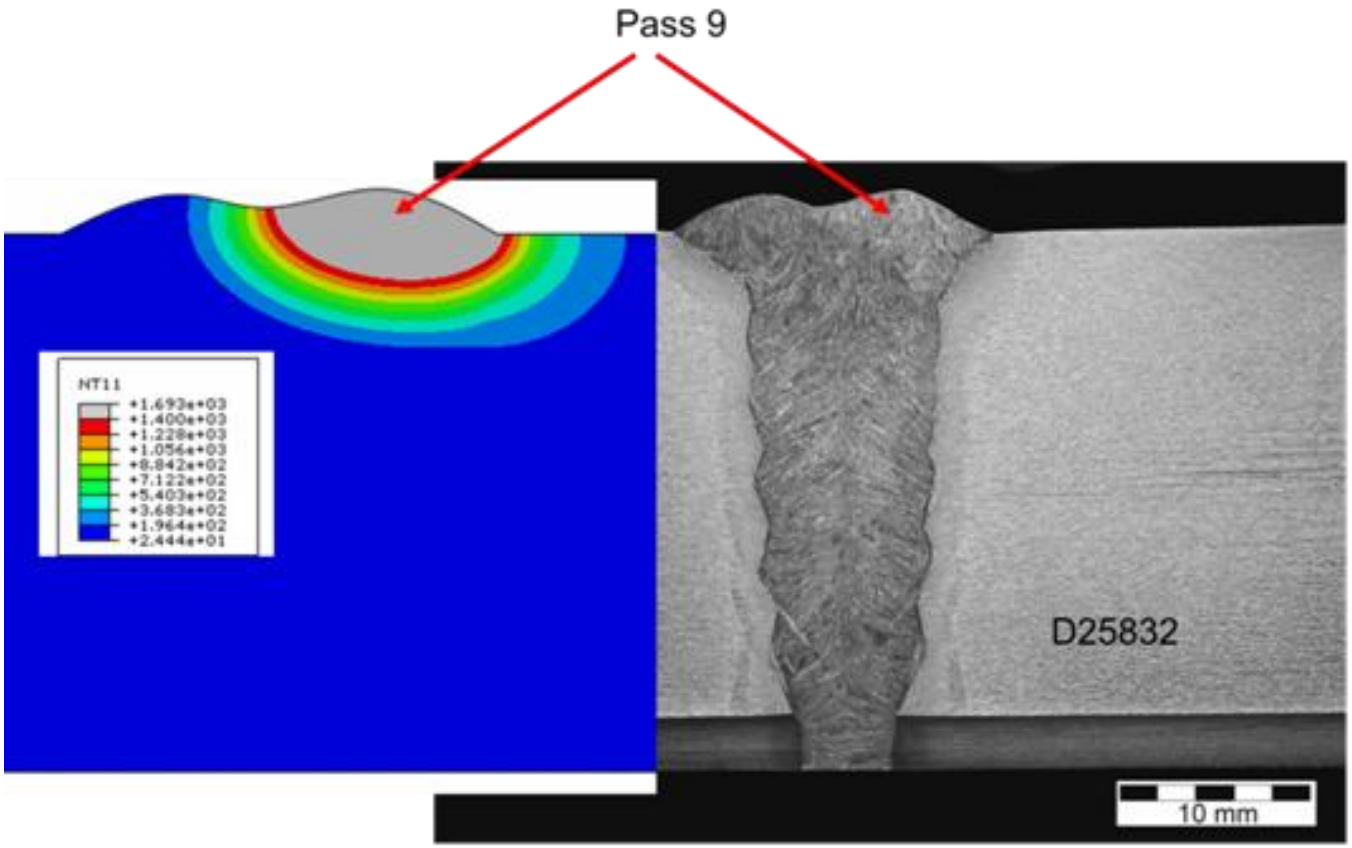
Models - SysWeld

- 2D axi-symmetric model



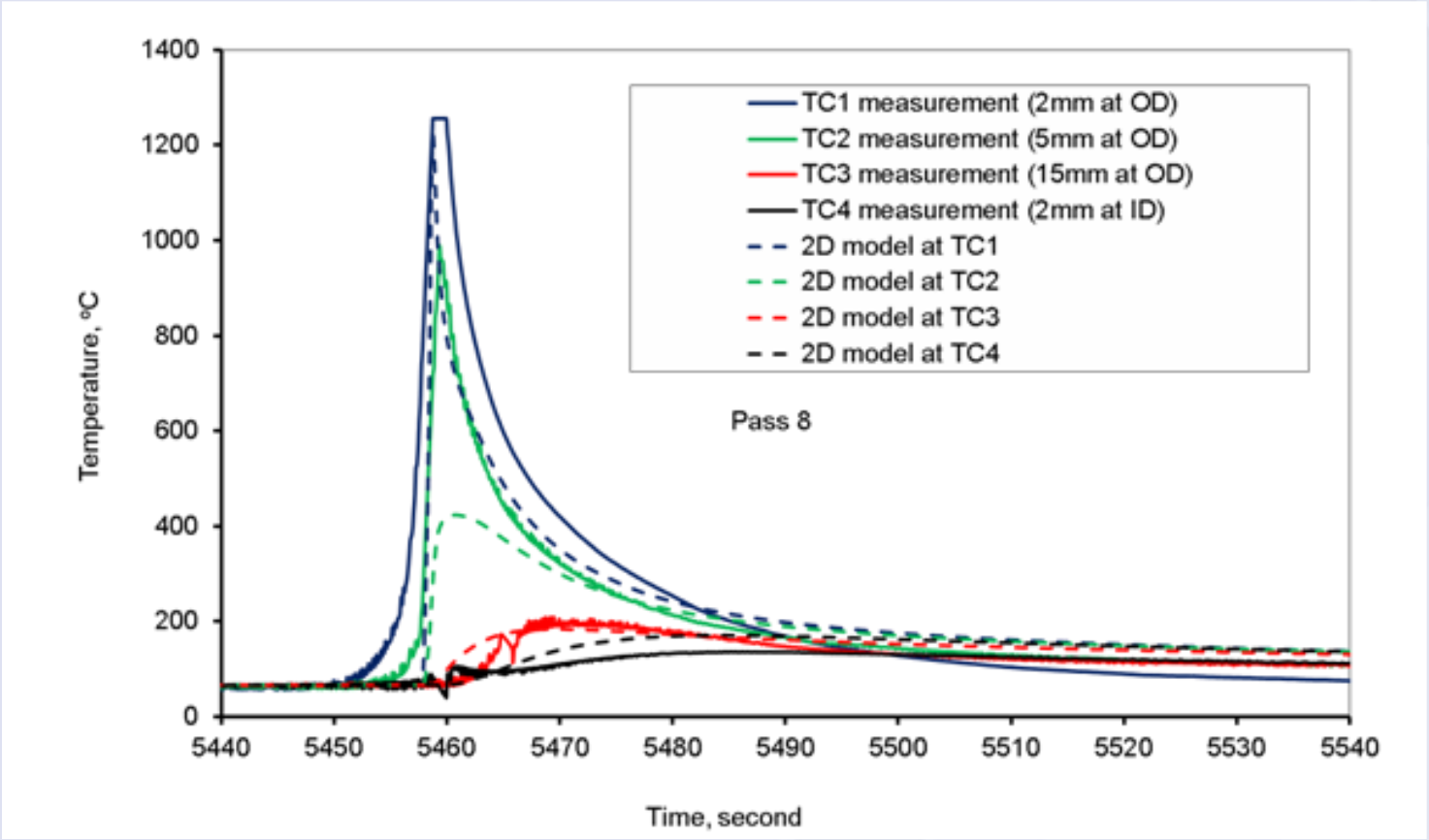
Heat Source Calibration - 1

- Abaqus 2D axisymmetric model: triangular amplitude



Heat Source Calibration - 2

- Abaqus 2D axisymmetric model: triangular amplitude



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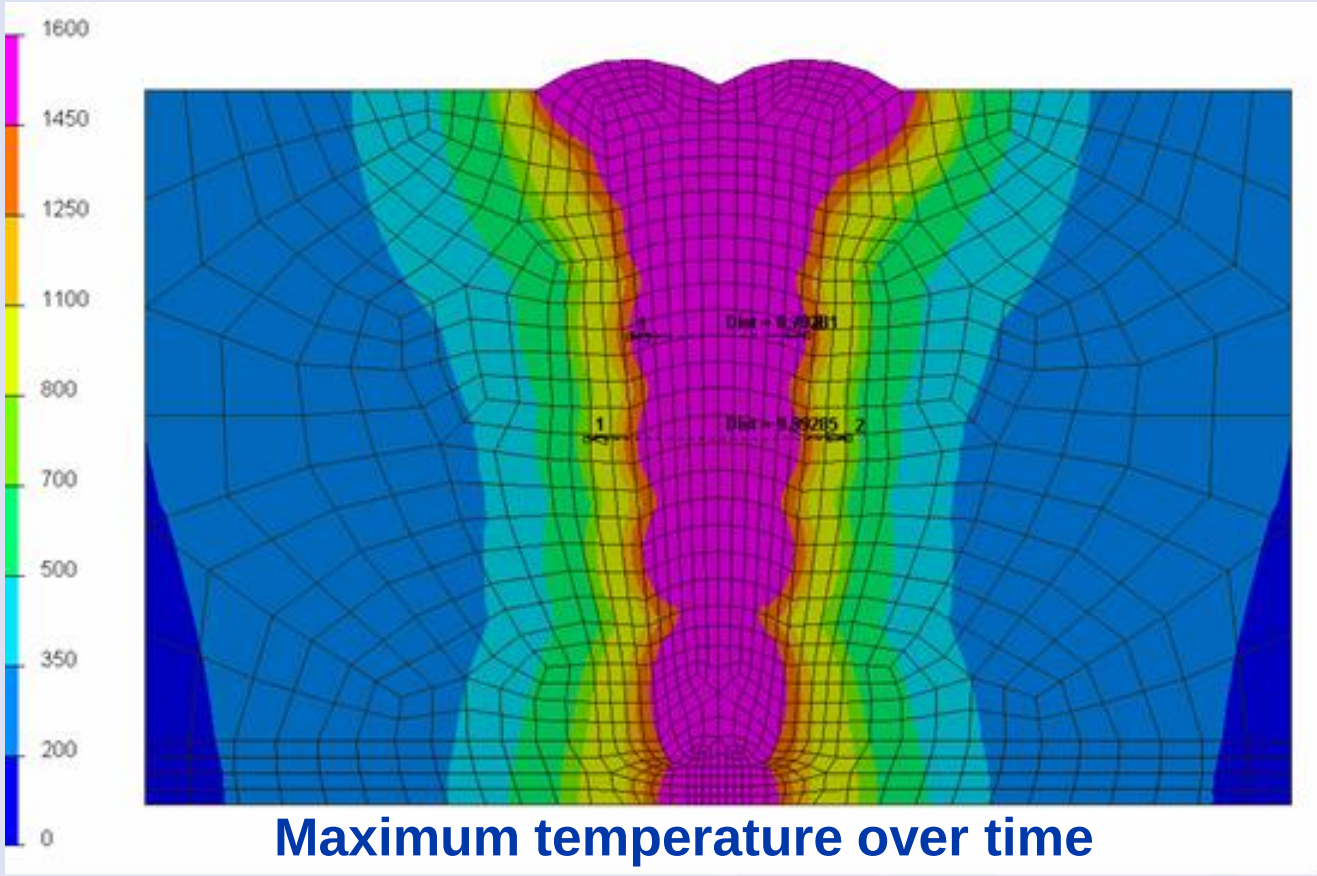
Heat Source Calibration - 3

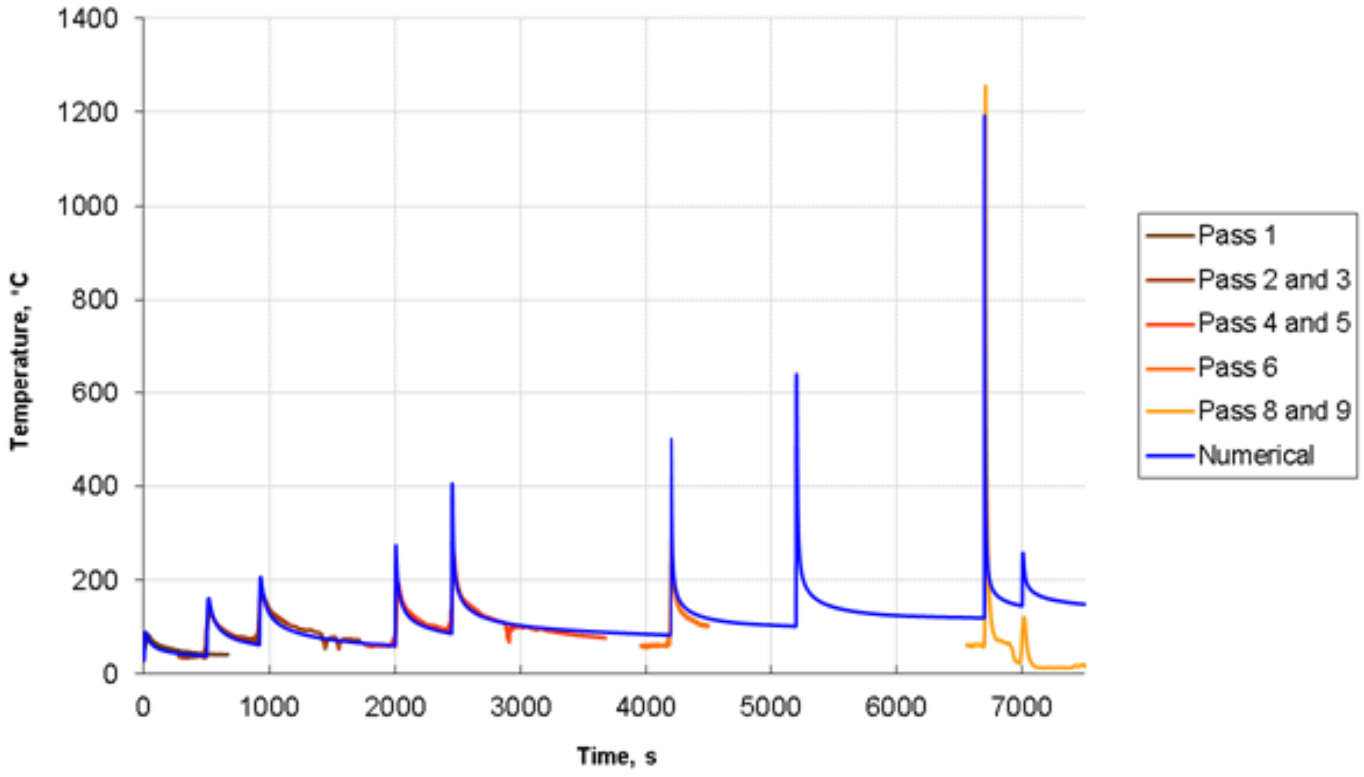
- SysWeld 2D axisymmetric model



Maximum temperature over time

Hest Source Calibration - 4

- SysWeld 2D axisymmetric model



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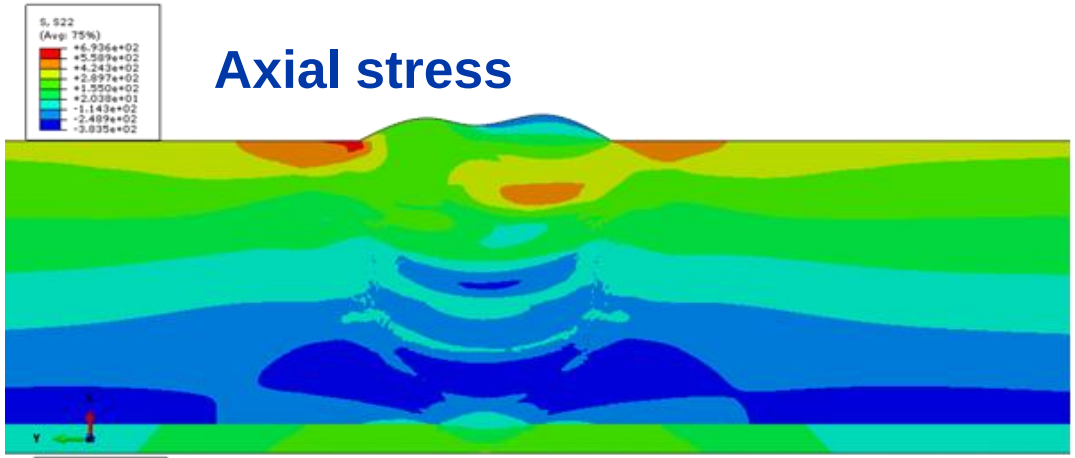
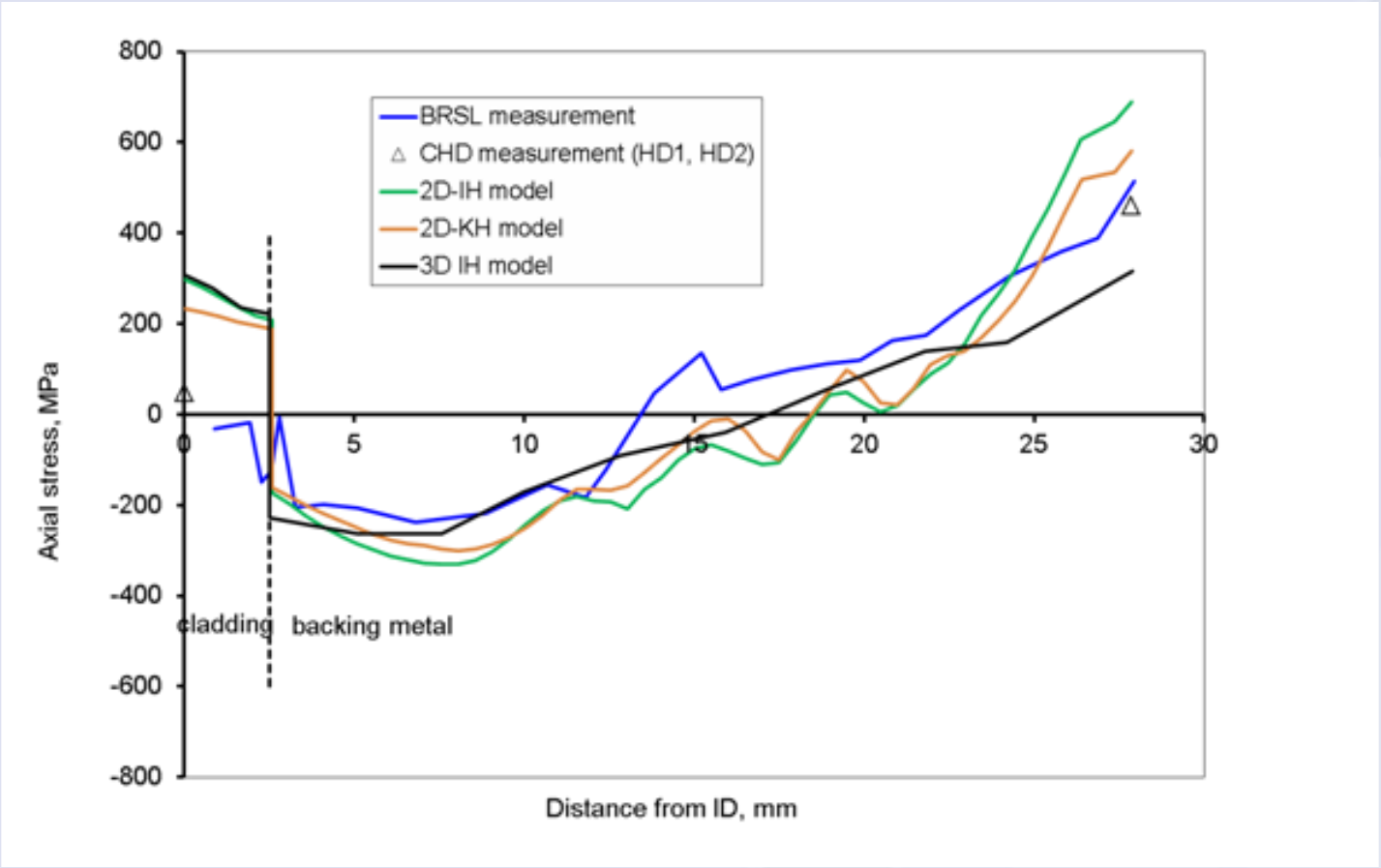
RS Prediction – Abaqus - 1

- 2D kinematic hardening



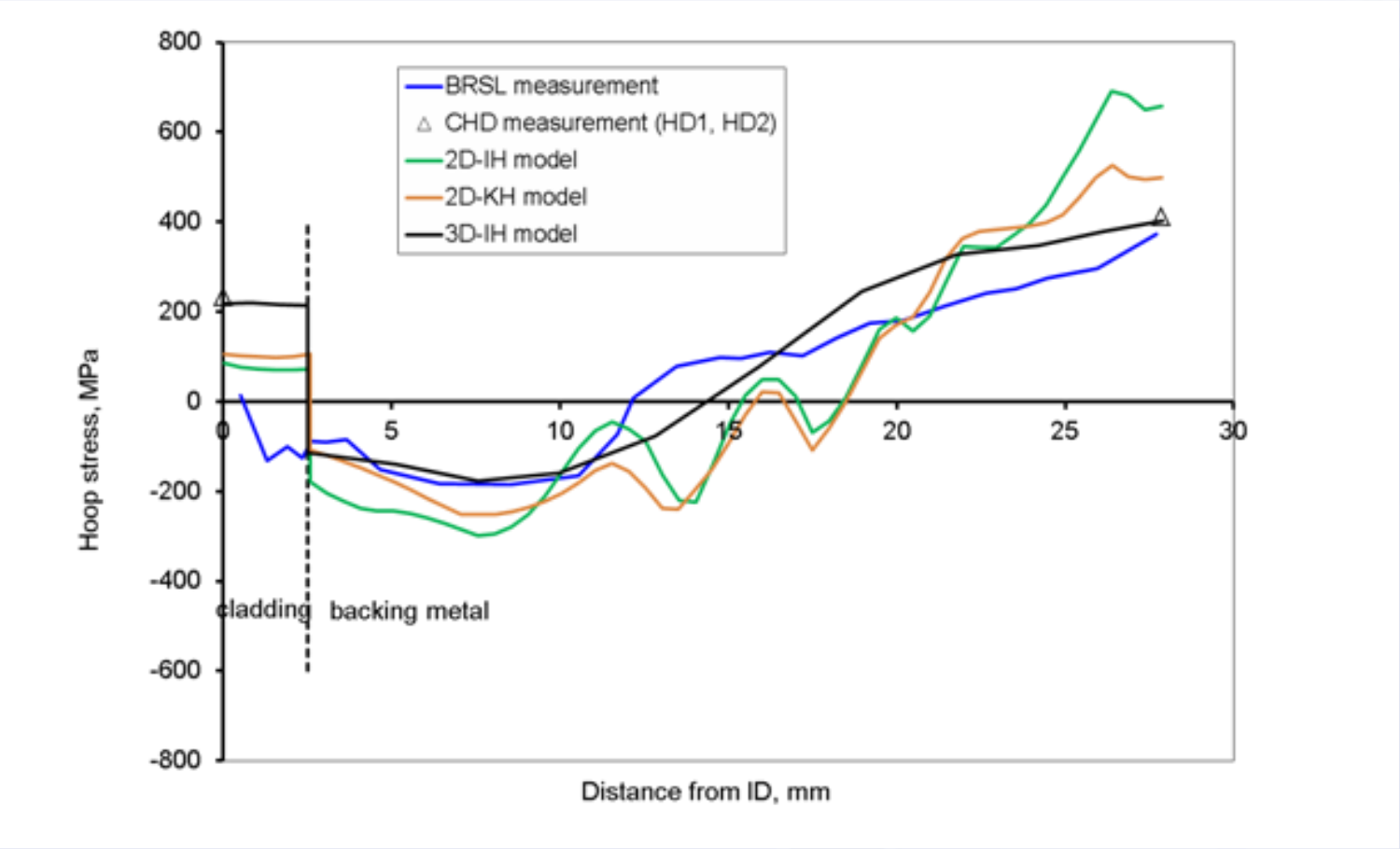
RS Prediction Abaqus - 2

- **Through-wall axial stress distribution**



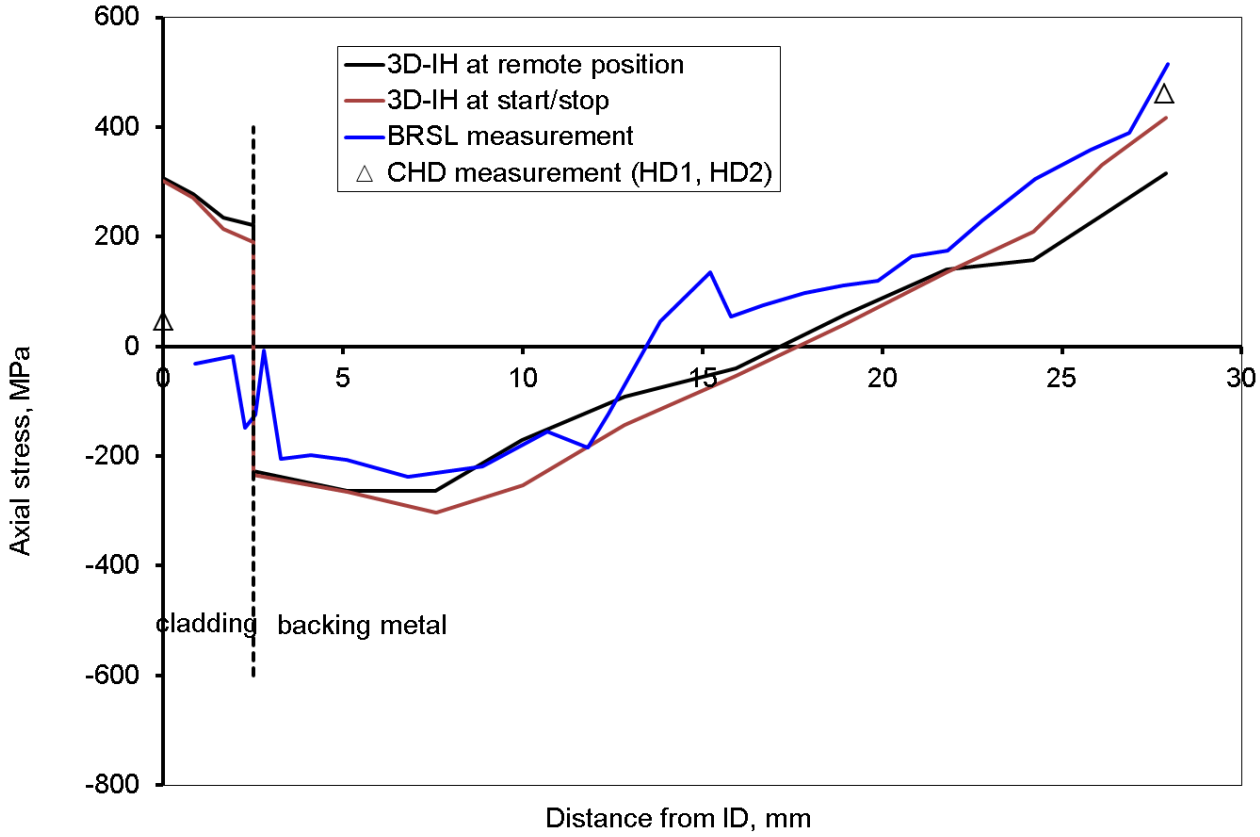
RS Prediction – Abaqus -3

- Through wall hoop stress distribution



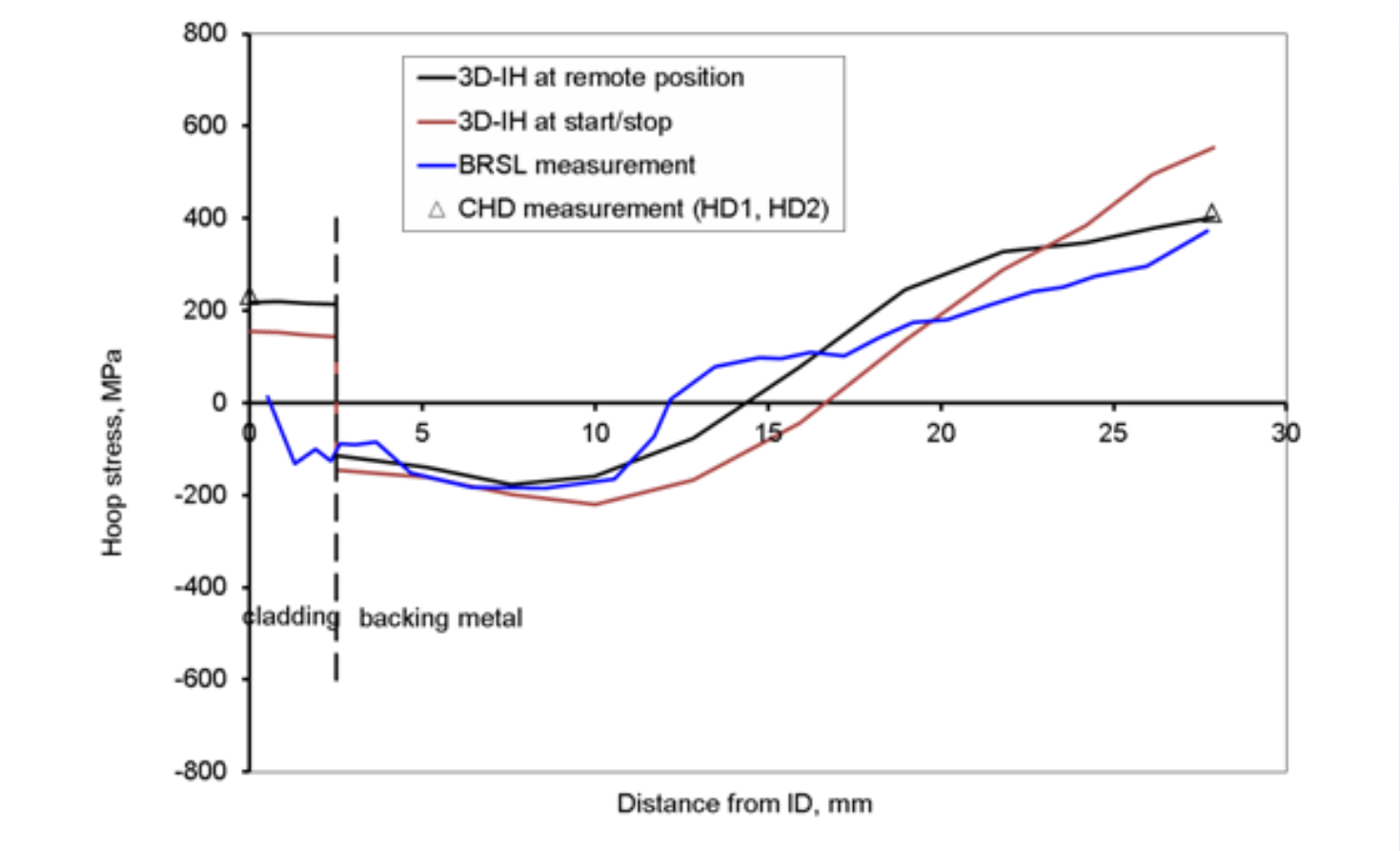
RS Predictions – Abaqus - 4

- Through-wall axial stress distribution



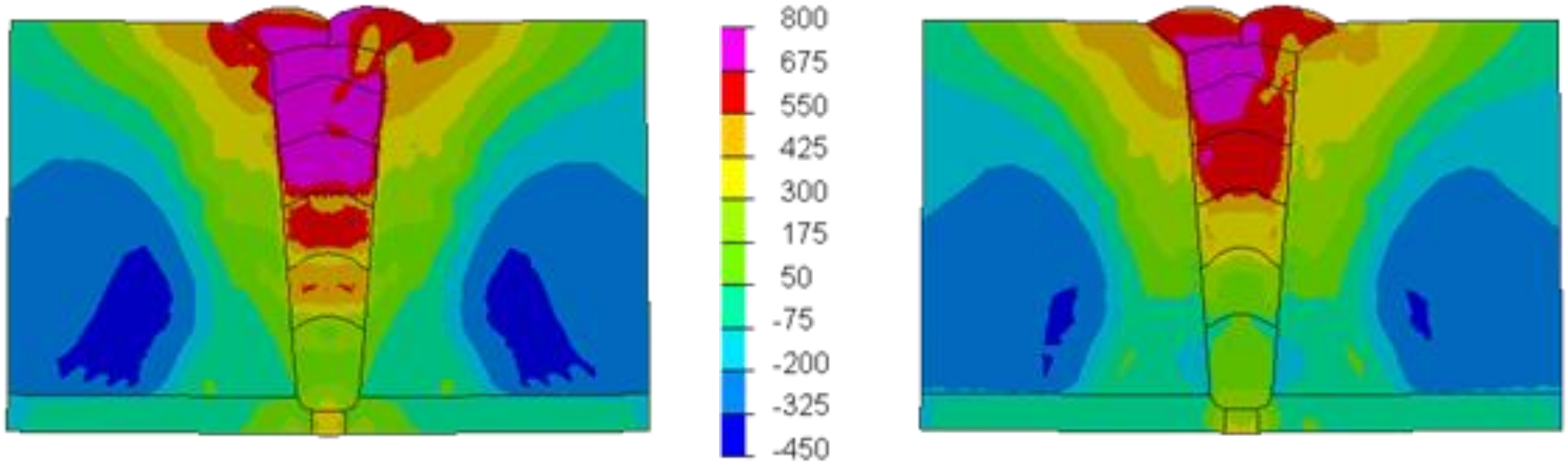
RS Predictions – Abaqus - 5

- **Through-wall hoop stress distribution**



RS Predictions – SysWeld -1

- **Hoop stress**

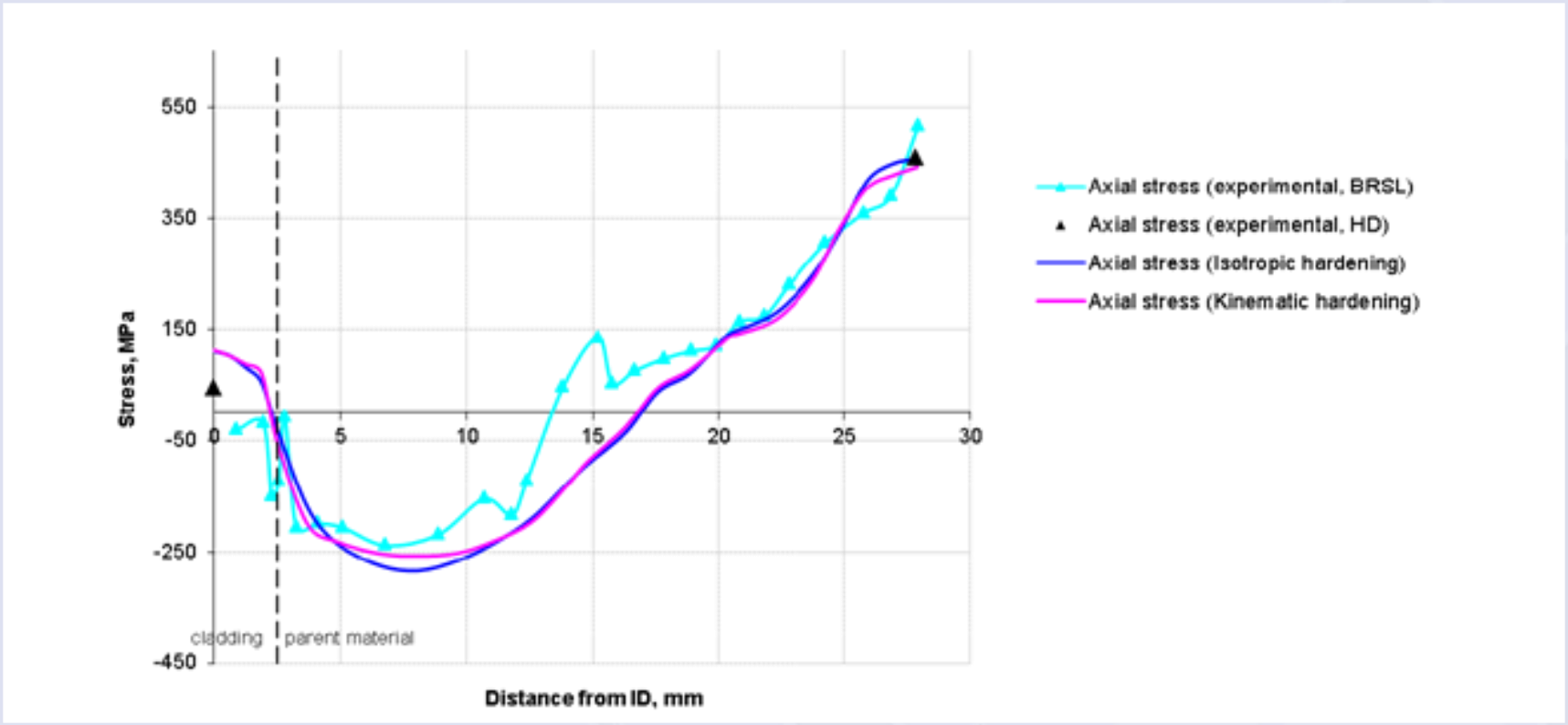


Isotropic hardening

kinematic hardening

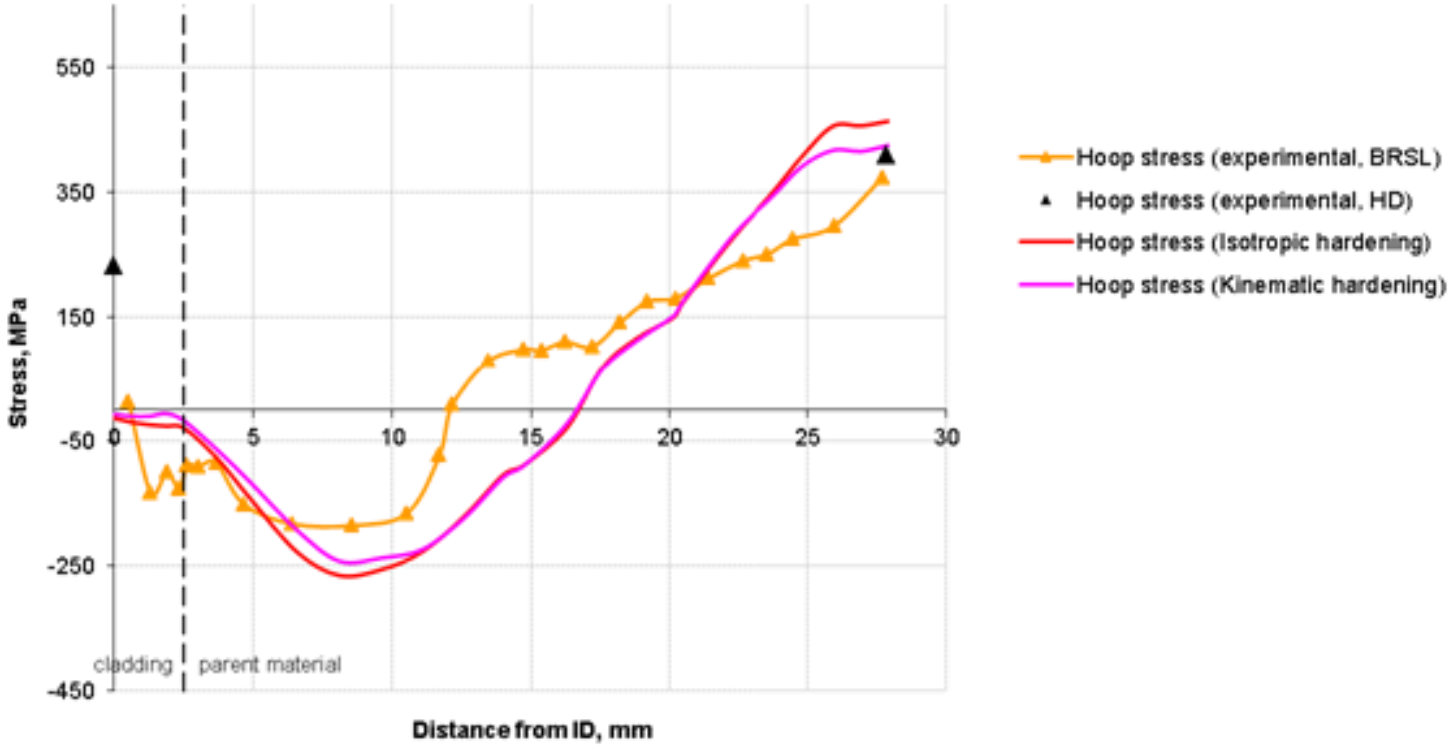
RS Predictions – Sysweld - 2

- **Through-wall axial stress distribution**



RS Predictions – Sysweld - 3

- Through-wall hoop stress distribution



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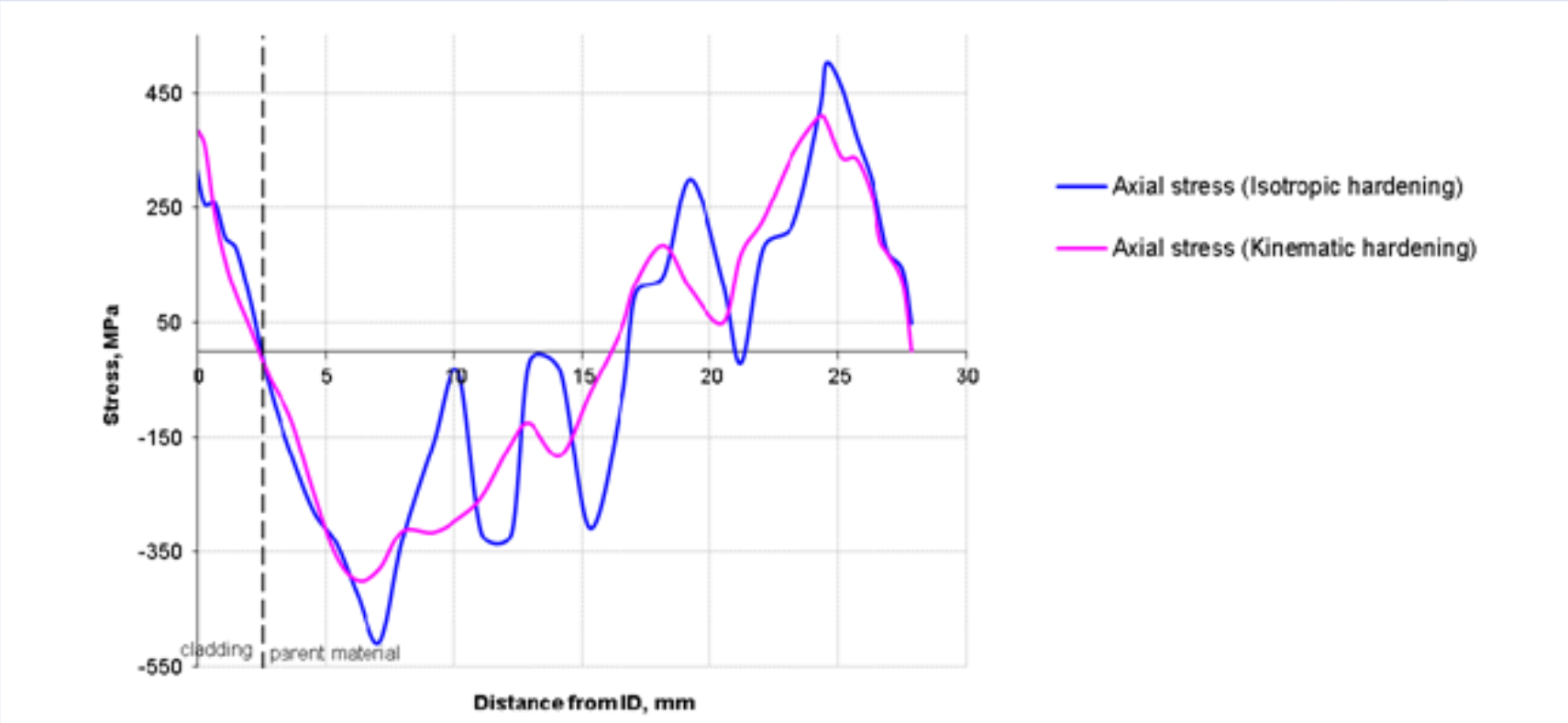
RS Predictions – Sysweld - 4

- Through-wall axial stress distribution at centre of weld



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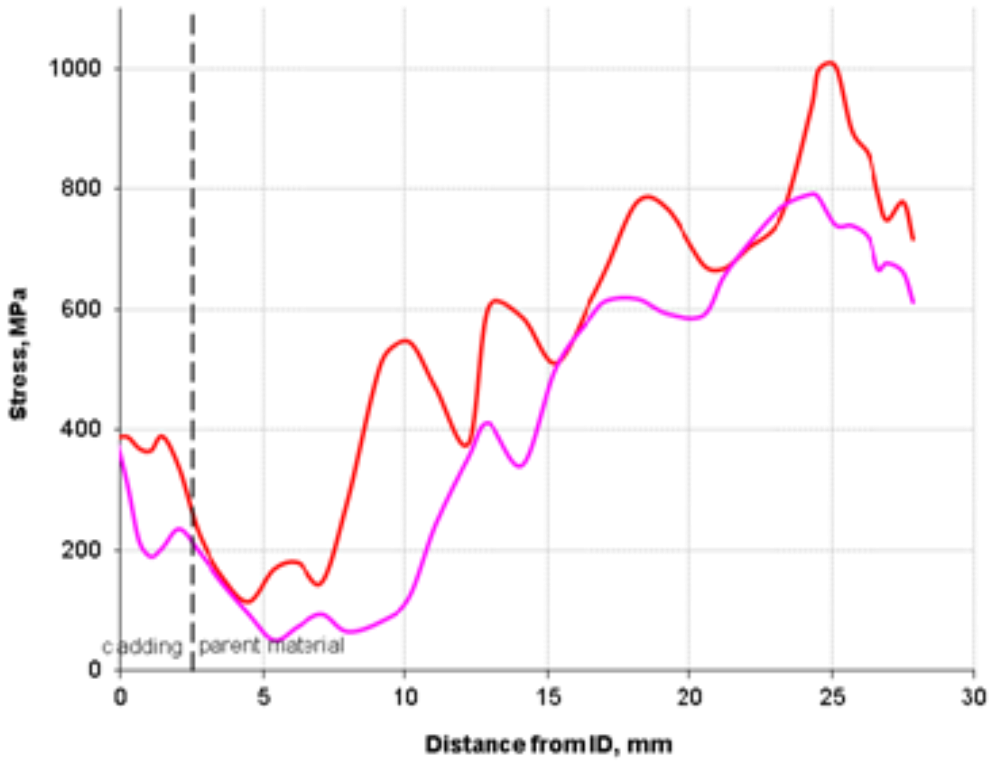
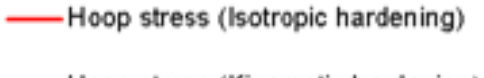
RS Predictions – Sysweld - 5

- Through-wall hoop stress distribution at centre of weld





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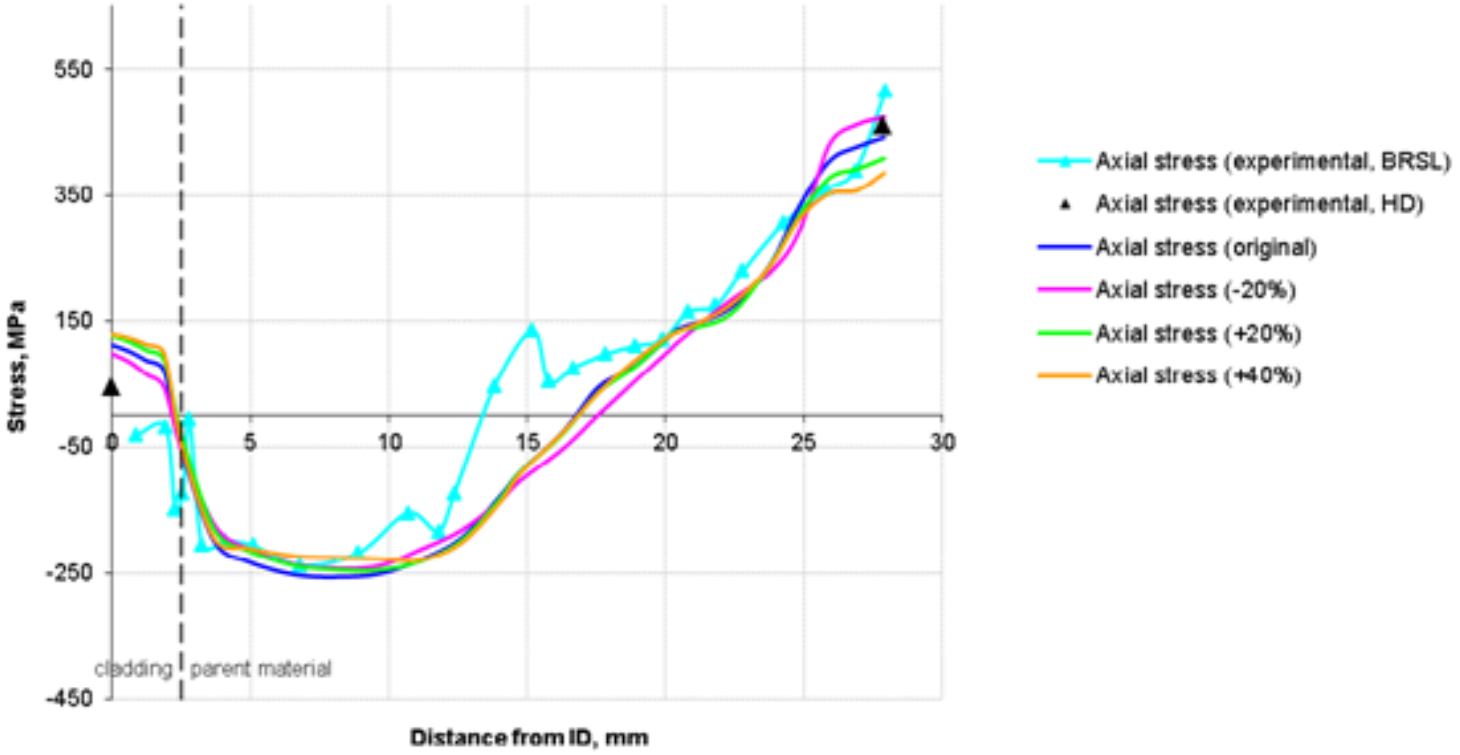
RS Predictions – Sysweld - 6

- **Effect of heat input on through-wall axial stress distribution**



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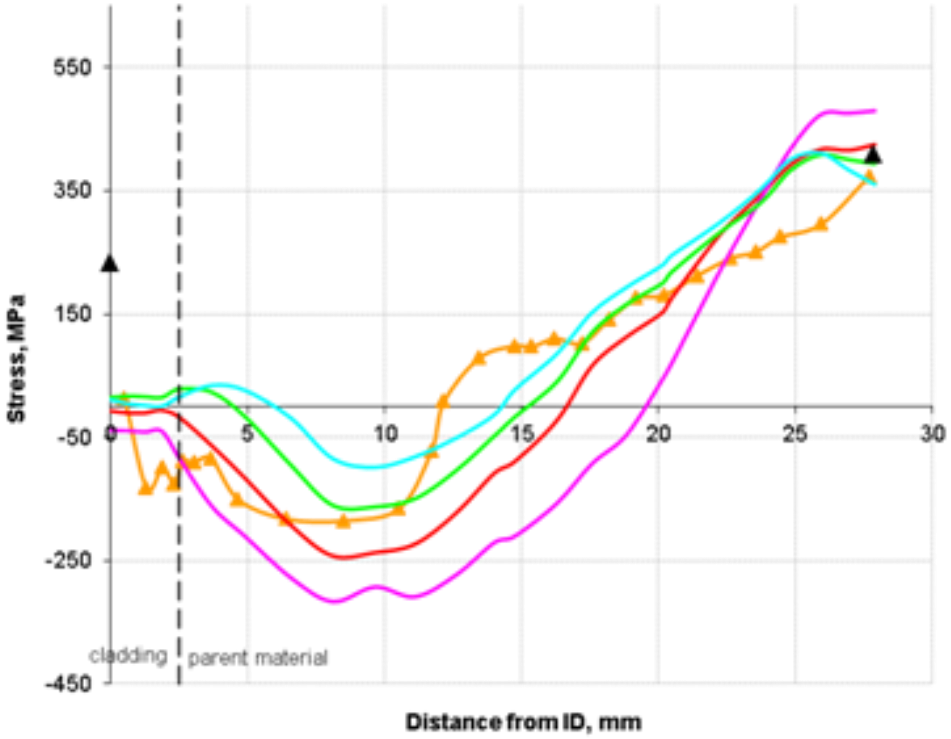
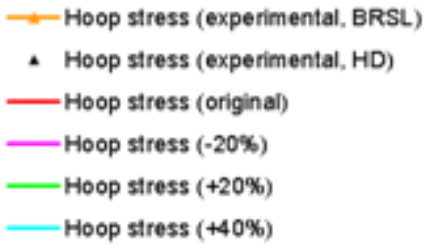
RS Predictions – Sysweld - 7

- Effect of heat input on through-wall hoop stress distribution





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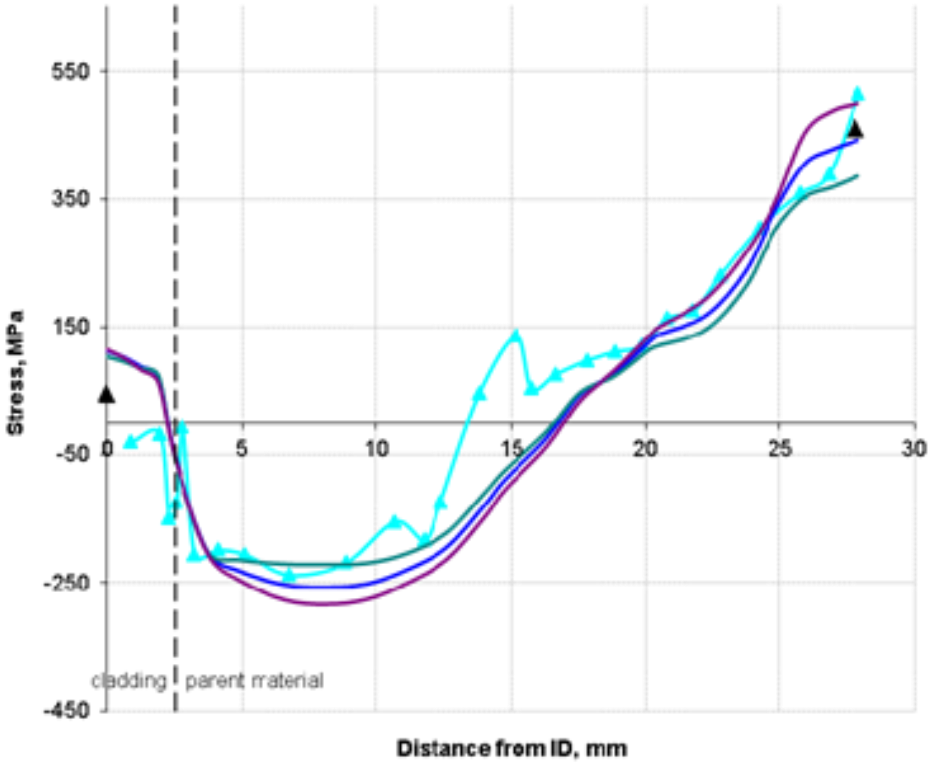
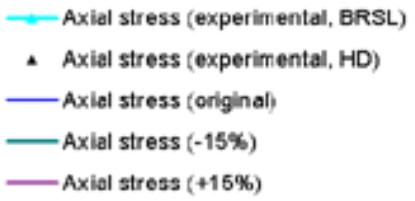
RS Predictions – Sysweld - 8

- Effect of yield stress on through-wall axial stress distribution





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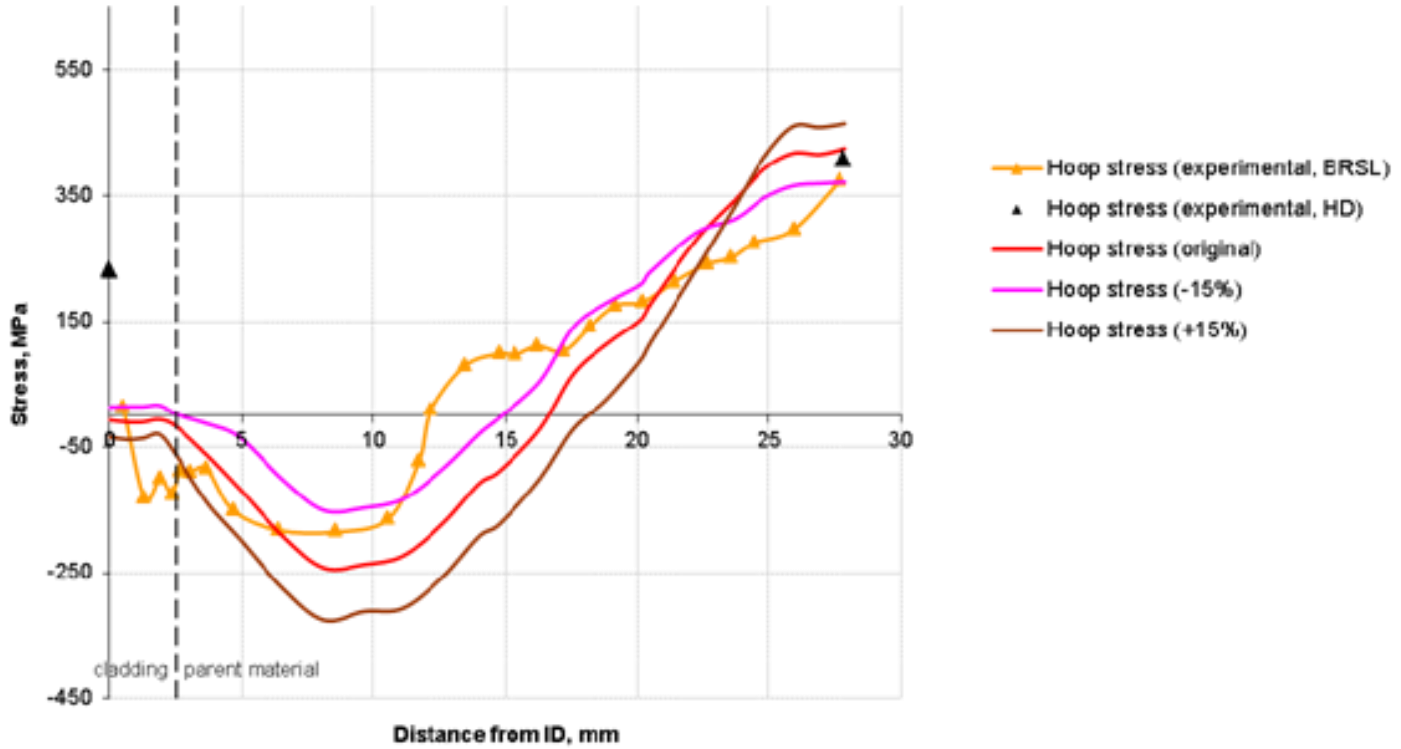
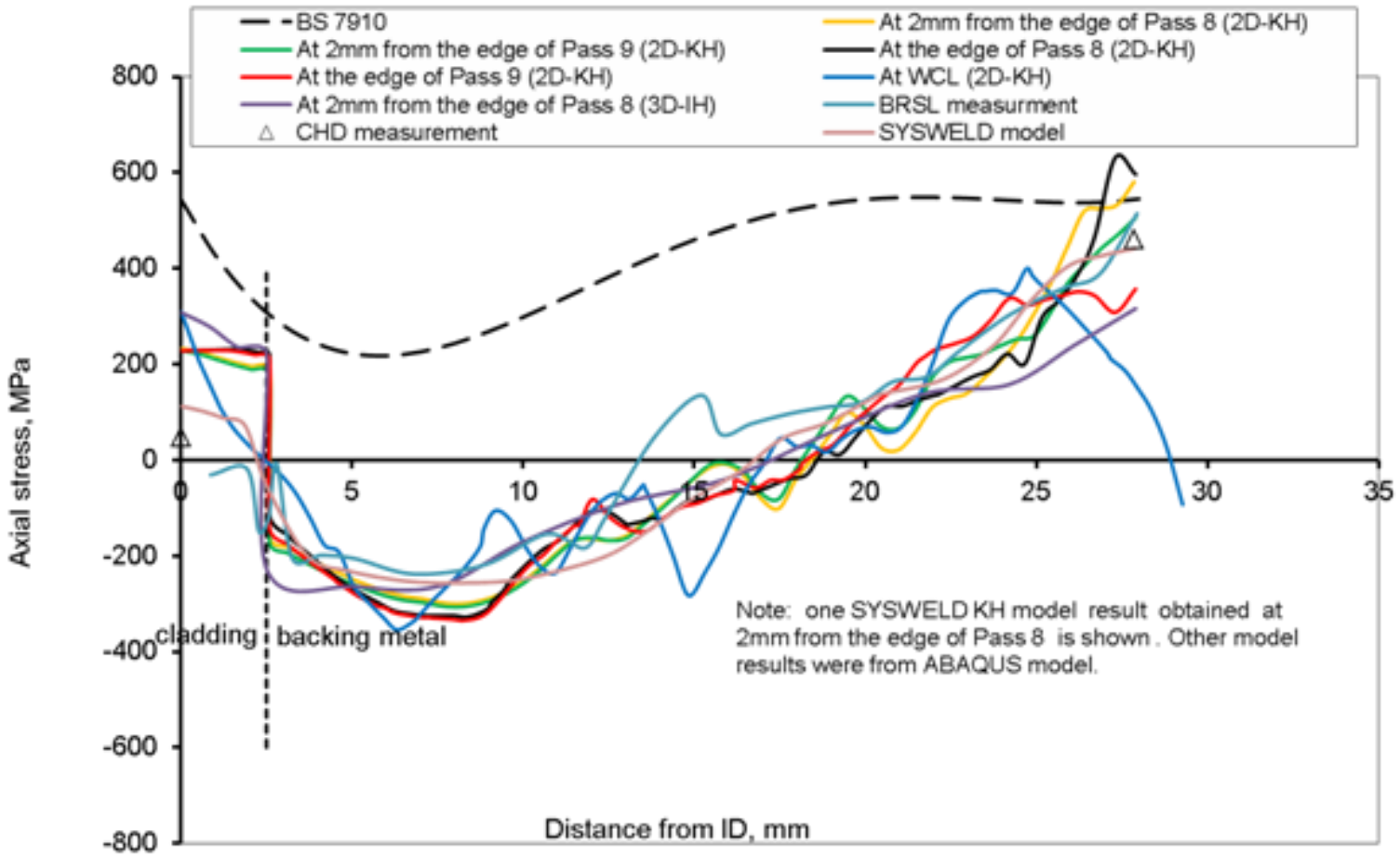
RS Predictions – Sysweld - 9

- Effect of yield stress on through-wall hoop stress distribution



Summary – Predicted Axial Stress



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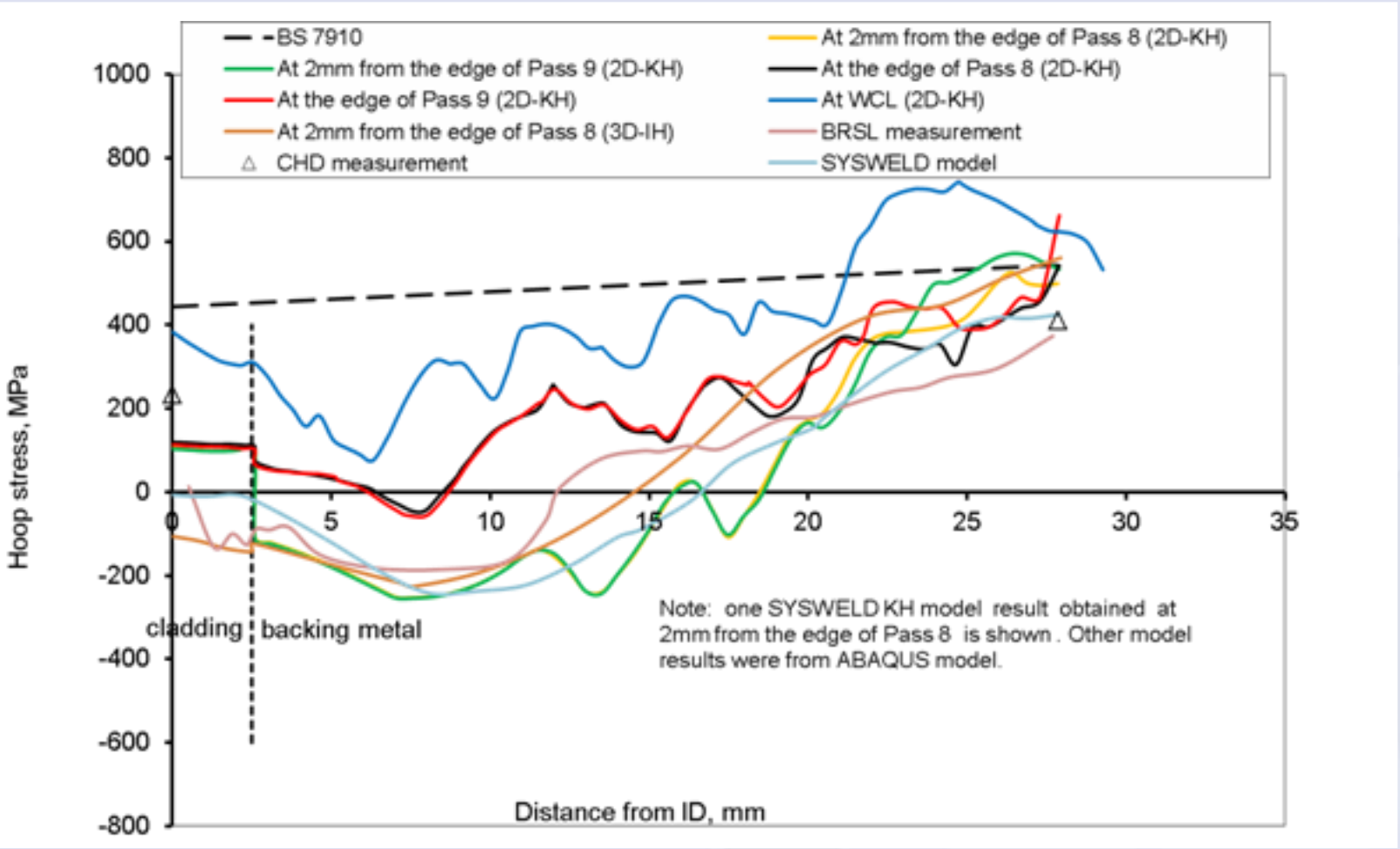
Summary: Predicted Hoop Stress



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Conclusions

- ABAQUS and SYSWELD successfully predict welding residual stress in a clad pipe girth weld. With proper calibration of the FE models of welding heat transfer analysis the FE models analysed with ABAQUS and SYSWELD were shown to provide reasonable agreement between the measurement and prediction residual stresses in a clad pipe girth weld region. SYSWELD was developed to simulate welding so the definition of a Goldak heat source is easier than it is in ABAQUS.
- The through-wall distributions of residual stress from the measurement and the ABAQUS and SYSWELD models were generally bounded by the BS 7910 solutions for plain pipe girth welds, except in a small region near the outside surface of the pipe.
- The weld start/stop was shown to have profound influence on the through-wall distribution of residual stresses, with the peak tensile values on the outside surface increased by over 30%.
- It was found that accurate calibration of FEA heat input is essential, as minor changes in the heat input led to significant changes in the predicted residual stress. The type of hardening model was found to be a large influence on the predicted residual stresses at the centre of the weld. Using the correct value for the yield stress is important as well, as small changes in the yield stress strongly affected the predicted residual hoop stress.

- **THANK YOU FOR YOUR ATTENTION**

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