NeT–TG6: Three superimposed Alloy 82 weld beads on a plate Alloy 600 nickel-base superalloy using TIG

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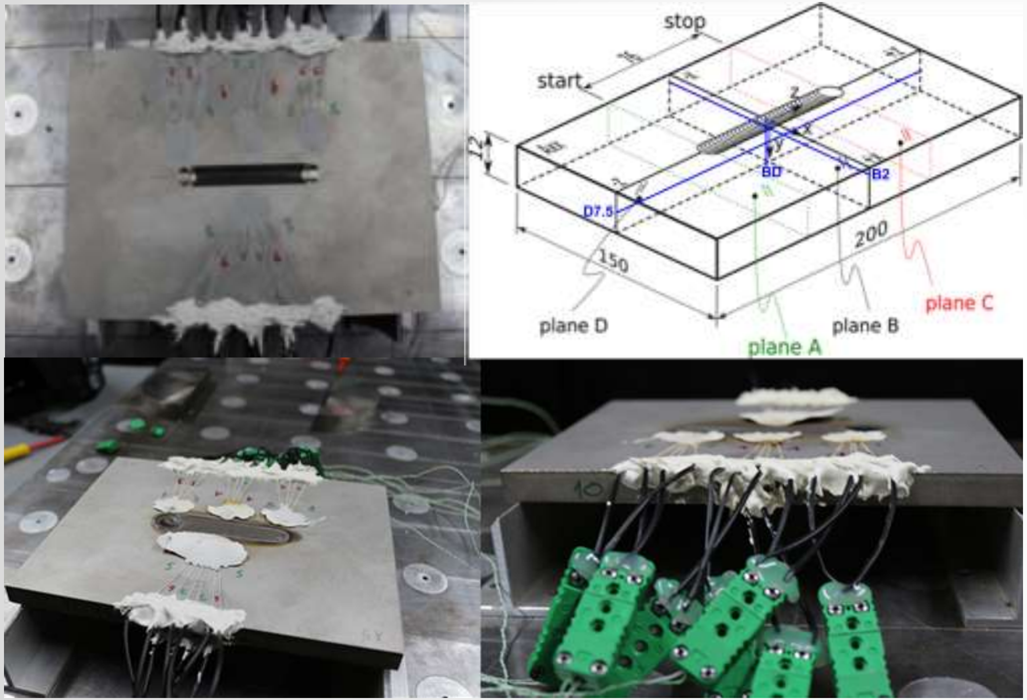
Lay out

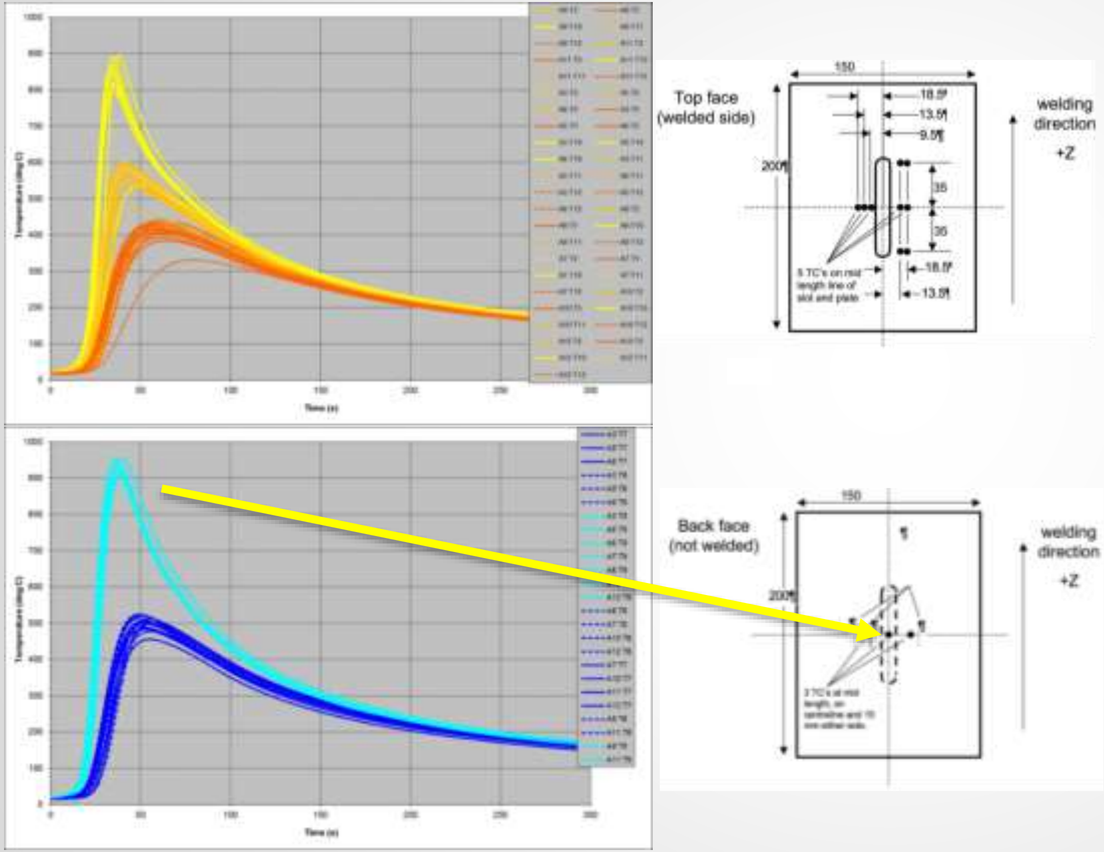
- Overview of the NeT–TG6 specimen
- Material Characterization
- Residual Stress Measurements
- Finite Element Modelling
- Final Remarks

Overview of NeT-TG6
Manufacture of specimens



- **Automated TIG welding** performed by EdF in Chatou, France using a robotic arm
- **NeT–TG6 Specimen:** Three superimposed Inconel 82 weld beads on a plate Alloy 600 nickel-base superalloy using TIG
- **9 specimens** manufactured using an array of 12 thermocouples (TC) on predefined spots

Mid-length thermocouple histories

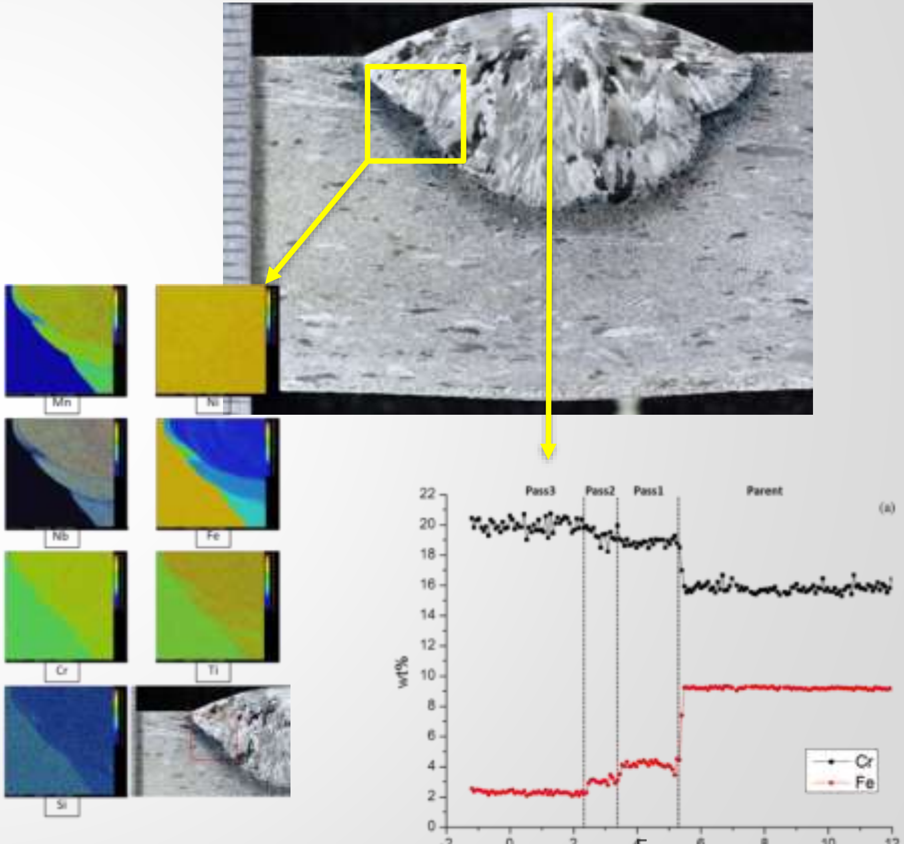


High repeatability of temperature rises measured at mid-length in the 9 welded specimens

High heat input!
Back face underneath the weld reaches ~900°C

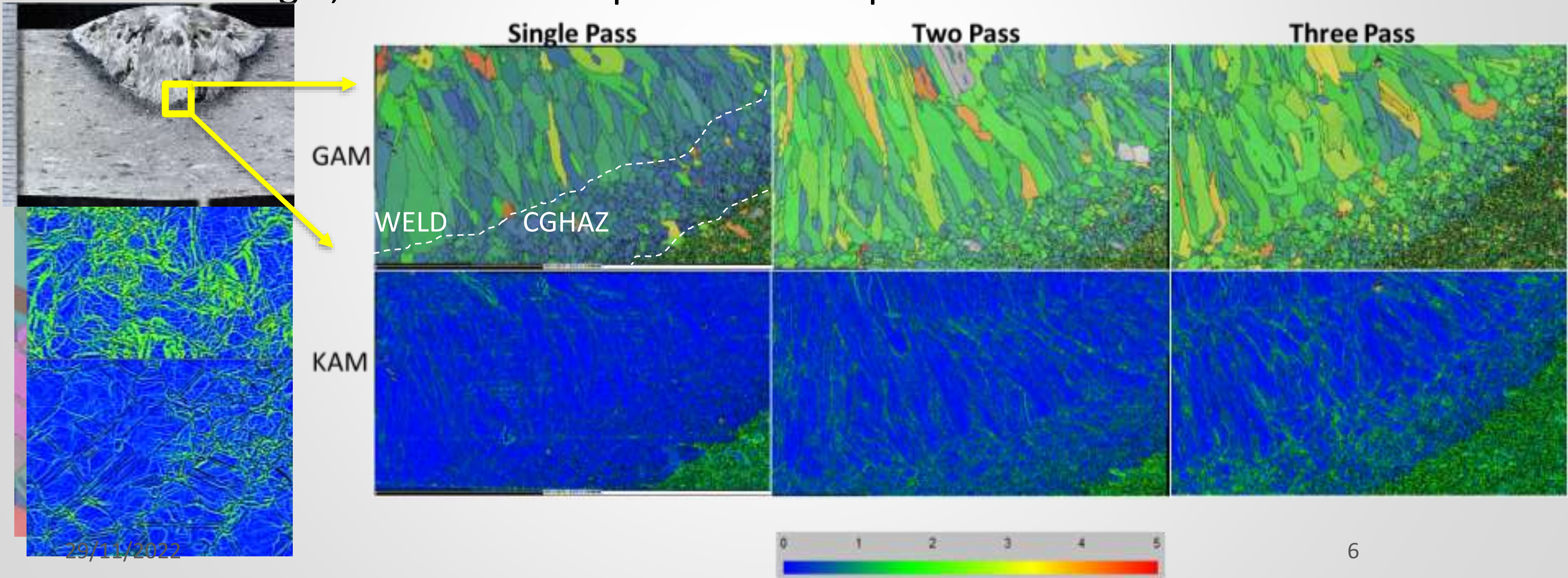
Material Characterization

- Metallography → Study the shape and size of different beads
- Chemical Composition Studies → Study the Dilution effects
- Micro-indentation Studies → Identify different thermo-mechanical histories
- Electron Back-Scattered Diffraction (EBSD)→ Measure Grain Size and Dislocation Density



EBSD – Qualitative Mapping of Plastic Strain

Qualitative mapping of the accumulated plastic strain in the weld and HAZ using Grain Average Misorientation (GAM) and Kernel Average Misorientation (KAM) metrics in single, two and three pass weld samples



Residual Stress Measurements

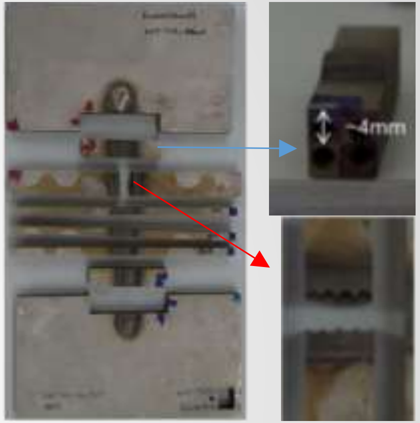
- Five neutron diffraction measurements

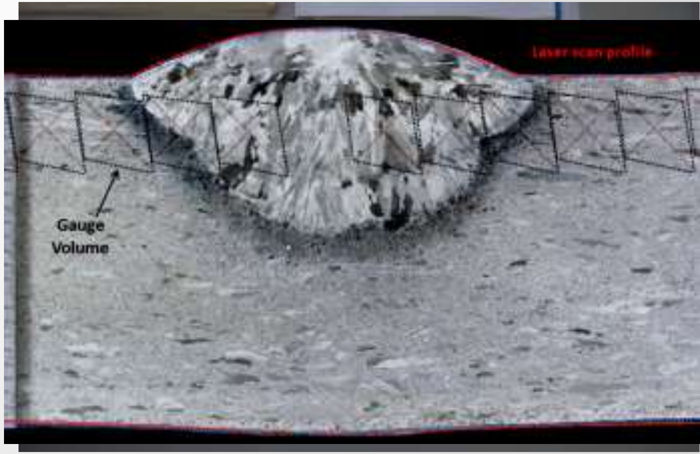
- STRESS-SPEC, FRMII
- E3, HZB
- ENGINX, ISIS
- SALSA, ILL
- KOWARI, ANSTO

- 3 different fitting strategies to infer strains

- Use of Stress Free Pins
- Use of Macrograph and Specimens scanned profiles
  → Estimate parent-weld fraction within gauge volume
- Calculate theoretical stress free lattice parameter / 2-theta
  → Zero Normal Stress

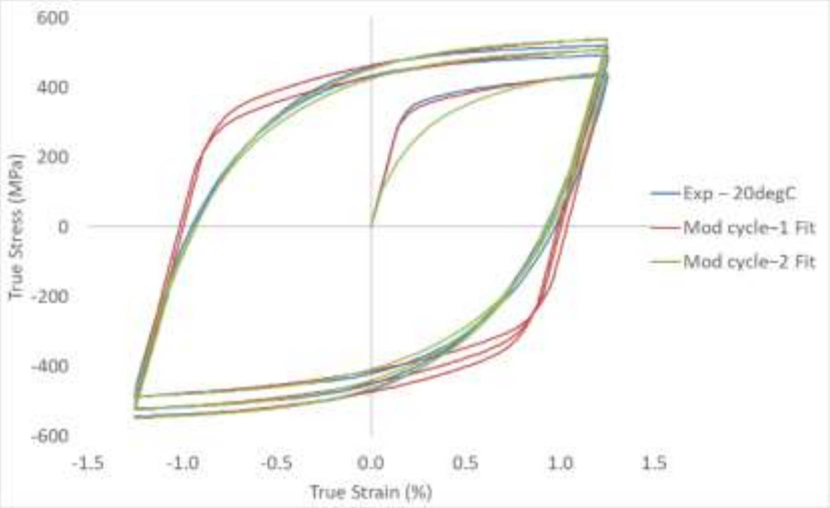
- Calculation of a robust Bayesian mean of the residual stresses
- Estimation of systematic uncertainty of neutron diffraction method (utilise TG4 benchmark too!)





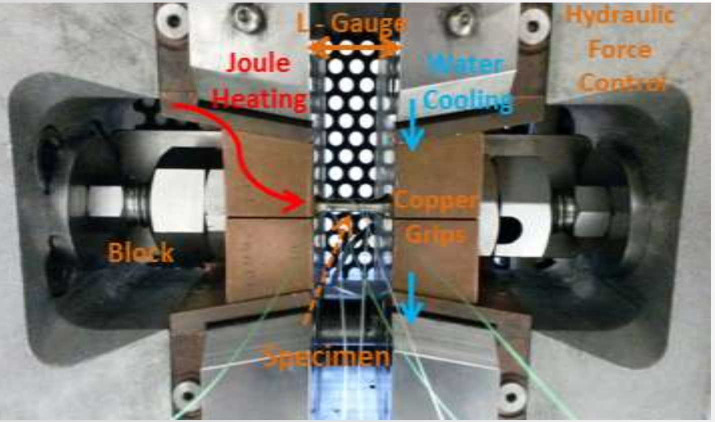
Material Constitutive Behaviour

- Fabrication of a weld pad made of Alloy 82
- Use of Alloy 600 of the same heat
- Isothermal Low Cycle Fatigue Tests performed in strain control mode
- Comparing the predicted responses after first load reversal of Chaboche mixed hardening material models with different parameter fitting strategies

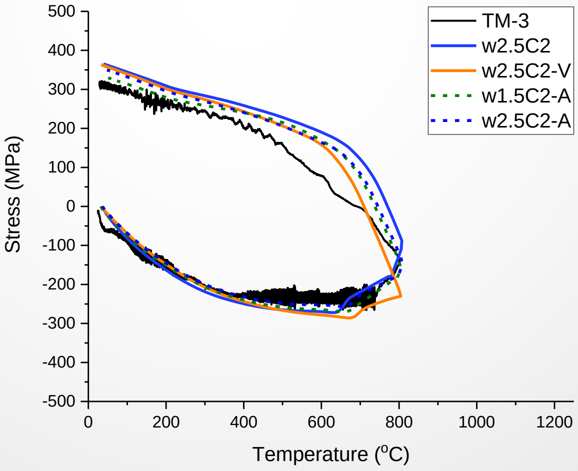


Thermo-mechanical Tests

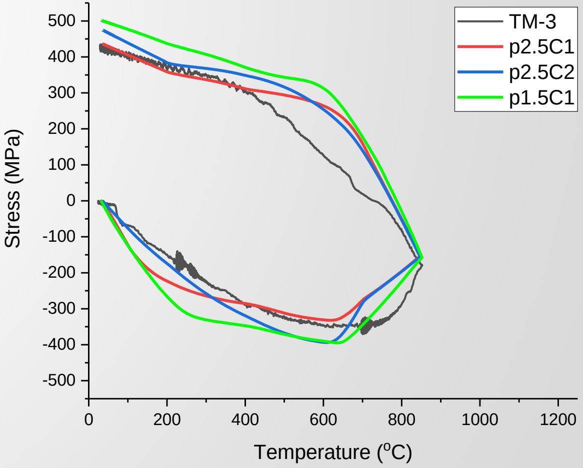
- Use of a Gleeble machine
- Application of representative thermal load cycles in a constraint specimen
- Measurements of several thermo-mechanical load cycles compared to the corresponding simulations for Alloy 82 and Alloy 600 using Chaboche mixed hardening model



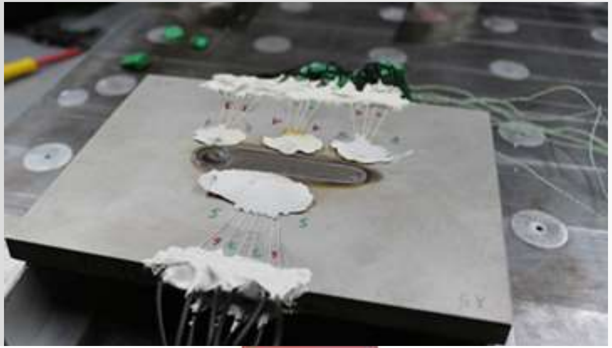
ALLOY 82

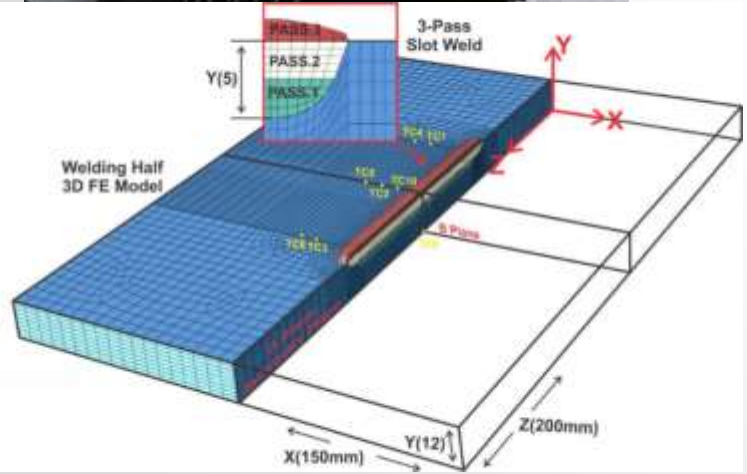


ALLOY 600



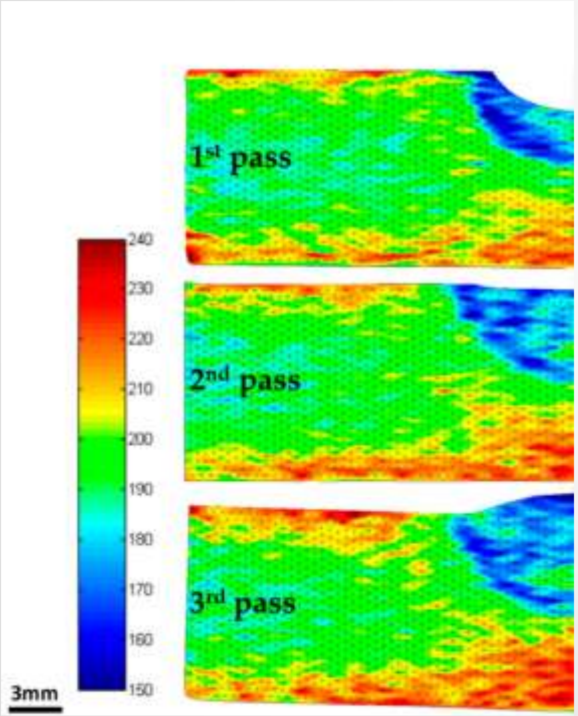
FE Modelling

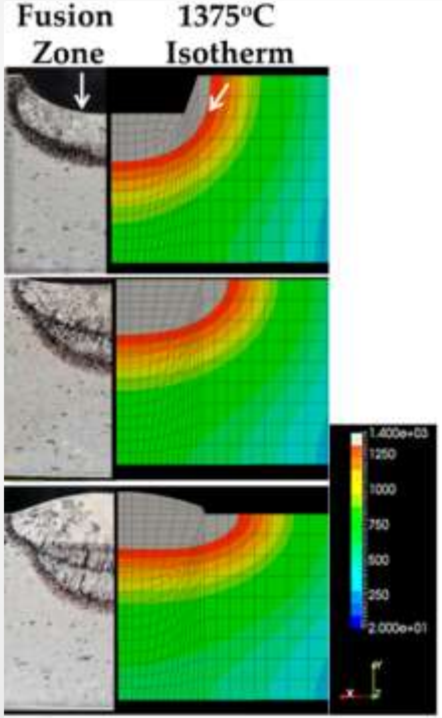




- ➢ Thermal analysis was calibrated using FEAT-WMT heat source modelling tool
- Macrograph of fusion boundary in transverse direction
- Thermocouple data
- Use of a single ellipsoid shape
- ➢ Mechanical analysis adopted the Chaboche constitutive models
- Isotropic and kinematic hardening
- Chaboche formulations

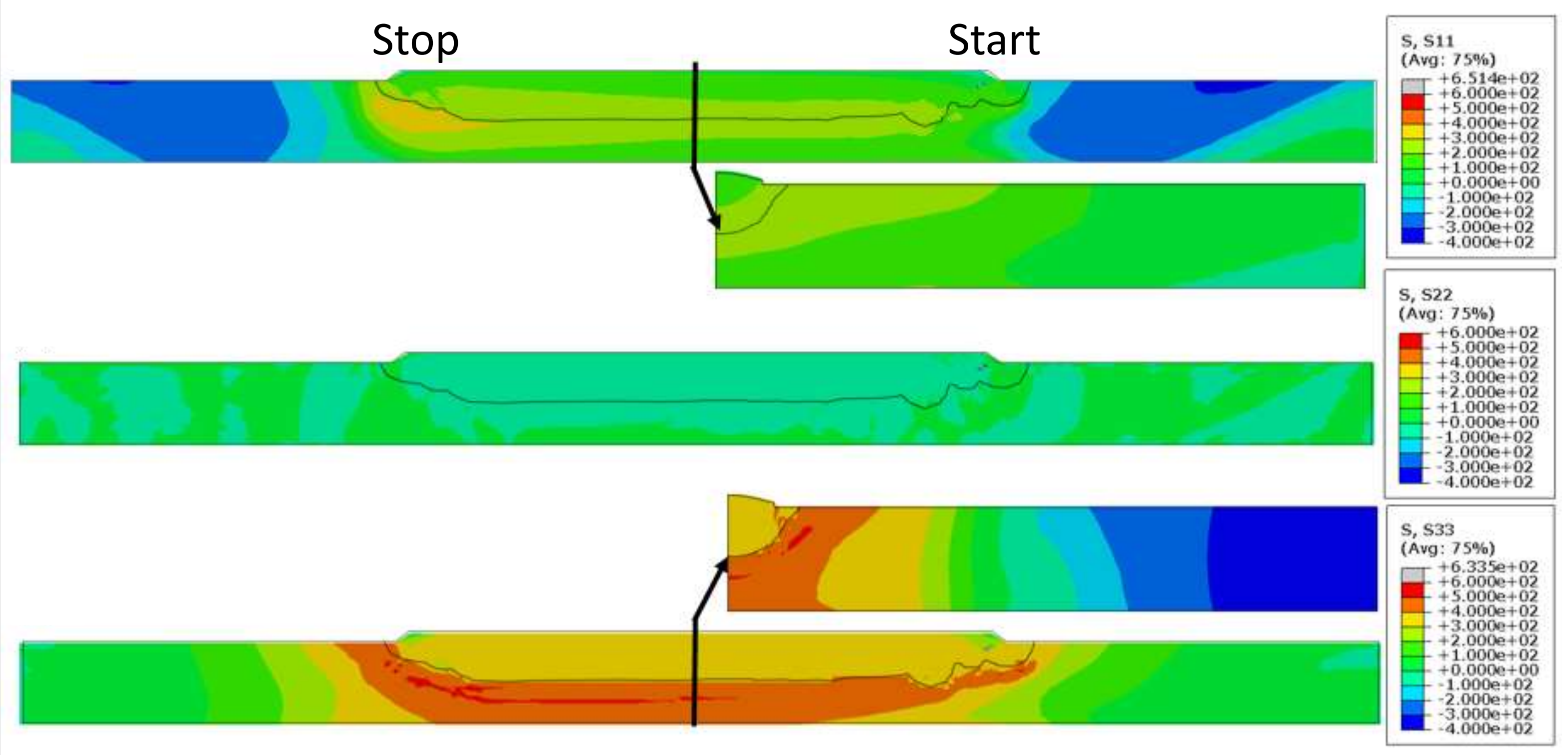
FE modelling
Thermal analysis



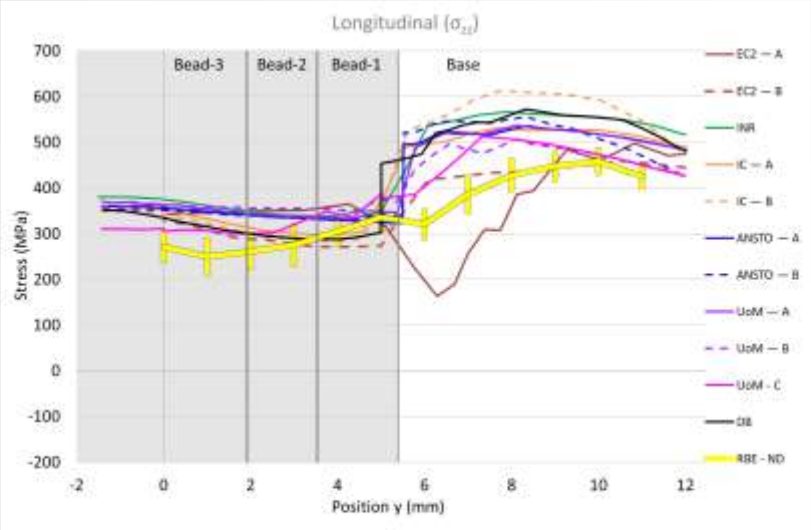


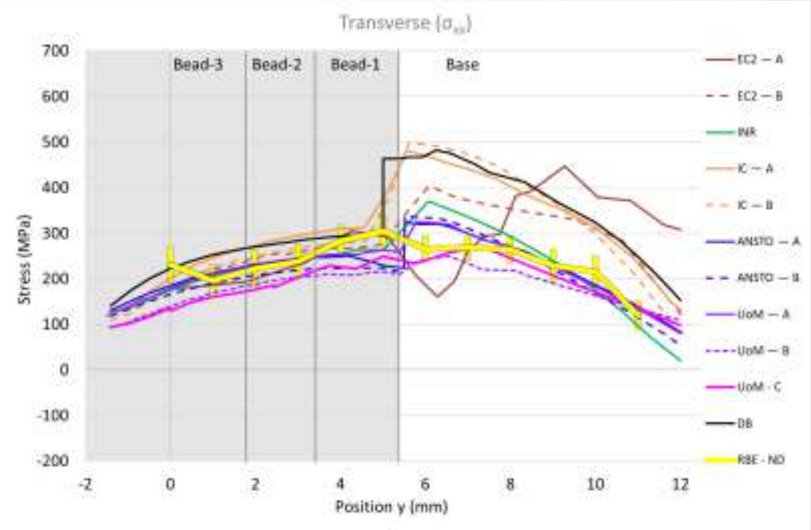
- Modelling of thermal transients of each weld pass
- Linking maximum Temperature reached with work hardening
- Selection of an appropriate Annealing Temperature

Residual Stress Contour Maps

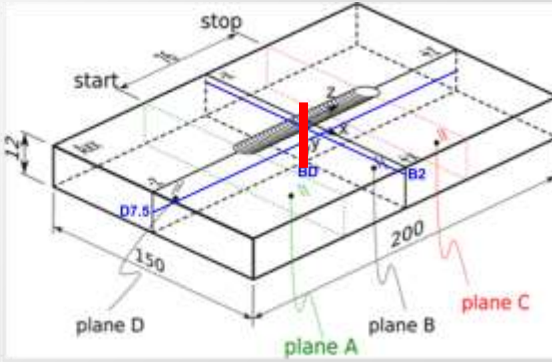


Line BD – Residual Stress Plots

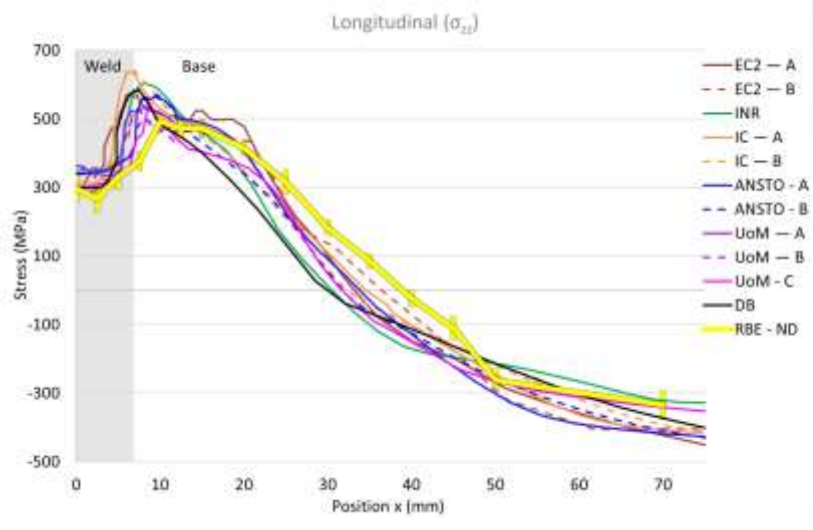


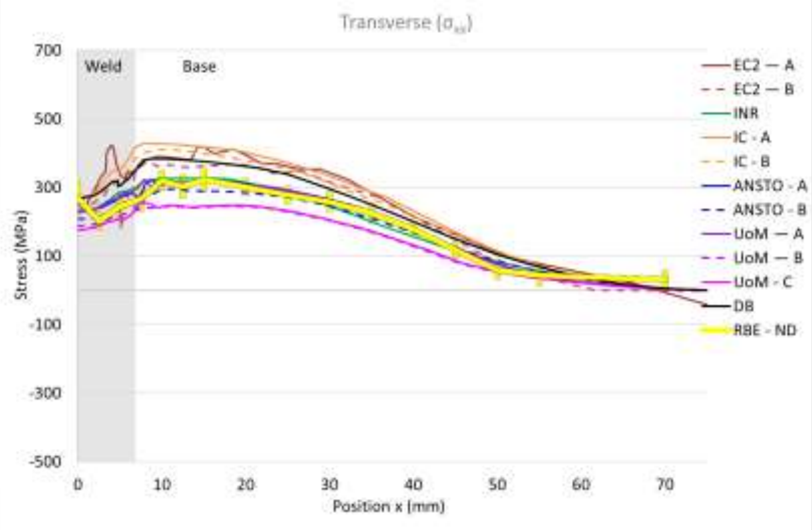


- Most simulations over-predict the longitudinal stress in the fusion zone and the adjacent parent zone
- Most of the simulations predict the transverse stress profile reasonably well

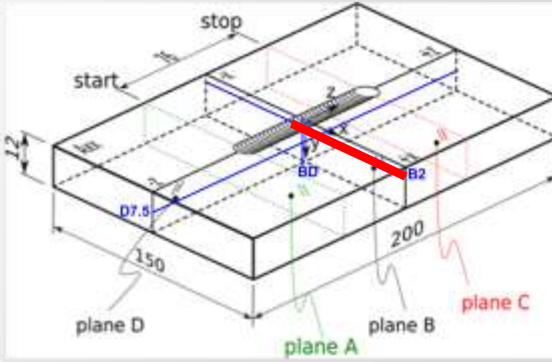


Line B2 – Residual Stress Plots





- Most simulations predict well both longitudinal and transverse stresses
- Scatter in predictions close to the weld fusion boundary
- Switch of parent/weld properties and CGHAZ



Final Remarks

The NeT -TG6 Specimen

- Multi-pass Alloy 82 & Alloy 600 nickel-base superalloys Dissimilar Metal Weld using TIG → High heat input (>900 °C reached at back face)
- The Alloy 82 weld metal is under-matched compared with the Alloy 600 parent plate
- The material seizes to harden at temperatures >1050 °C
- A soft re-crystallized coarse-grained heat affected zone adjacent to the fusion zone where temperatures exceeded ~1200 °C with different mechanical properties
- A fusion zone with very large grains and diluted parent into weld

Final Remarks

- The neutron diffraction residual stress measurement round robin undertaken on NeT-TG6 produced reliable robust Bayesian estimates of the residual stress field
- The predicted residual stresses were generally in good agreement with measured stresses Few areas that could be improved:

- Longitudinal stresses in the transition region between weld and parent material where the softened re-crystallized CGHAZ occurs
- A more sophisticated annealing scheme should be employed
- Shorter welds bead lengths led to over-predicted stresses due to the structural restraint in the weld region

Publications

- Akrivos, V., et al., On the neutron diffraction measurements of weld residual stresses in three-pass slot-weld (Alloy 600/82) and the assessment of the measurement uncertainty. Journal of Applied Crystallography, 2020. 53: p. 1181-1194 DOI: 10.1107/S1600576720009140.
- Wimpory, R. C., et al., Precise Measurement of Steep Residual Strain Gradients Using Neutron Diffraction in Strongly Absorbing Materials with Chemical Compositional Gradients. Materials Performance and Characterization, 2020. 7 (4): p. 488-503 DOI: 10.1520/MPC20170114
- Akrivos, V. and M.C. Smith, The thermo-mechanical behaviour of the Alloy 600 and Alloy 82 materials. Proceedings of the ASME 2018 Pressure Vessels and Piping Conference PVP 2018, 2018(84592) DOI: 10.1115/PVP2018-84592.
- Akrivos, V. and M.C. Smith, Material Characterization on the Nickel-Based Alloy 600/82 NeT-TG6 Benchmark Weldments. Proceedings of the ASME 2019 Pressure Vessels and Piping Conference PVP 2019, 2019(94017) DOI: 10.1115/pvp2019-94017.
- Akrivos, V., et al., A residual stress measurement and numerical analysis round robin on a three-pass slot nickel-base repair weld. Procedia Manufacturing, 2020. 51: p. 779-786 DOI: 10.1016/j.promfg.2020.10.109.
- Akrivos, V., et al., On the Accurate Prediction of Residual Stress in a Three-Pass Slot Nickel-Base Repair Weld by Numerical Simulations. Journal of Manufacturing and Materials Processing, 2022. 6 (3): p. 1-19 DOI: 10.3390/jmmp6030061
- Smith, M.C., et al., The NeT-Task Group 6 Weld Residual Stress Measurement and Simulation Round Robin in Alloy 600/82, Proceedings of the ASME 2016 Pressure Vessels and Piping Conference PVP 2016. 2016

Thank you!