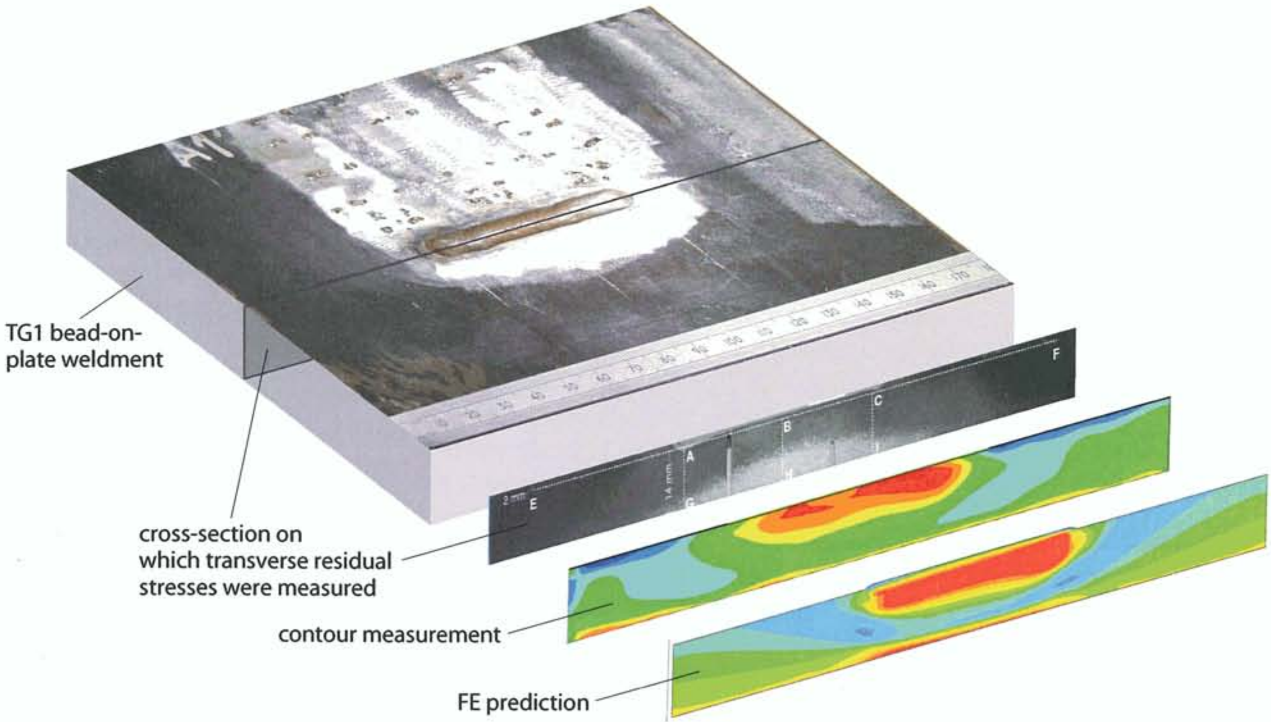
Network on Neutron Techniques Standardization for Structural Integrity

The mission of the European Network on Neutron Techniques Standardization for Structural Integrity (NeT) is to develop experimental and numerical techniques and standards for the reliable characterisation of residual stresses in structural welds.



Network Approach

Each problem is tackled by creating a dedicated Task Group (TG) which manages measurement and modelling round robin studies and undertakes synergistic interpretation of the results.

TG1, dealing with residual stresses around a single bead on a plate weld, has achieved outstanding success and is described here in some detail. Four other Task Group activites are also outlined.

Measurement Techniques

- Neutron and X-ray diffraction
- Small angle neutron scattering (SANS)
- Surface and deep hole drilling, contour method
- Metallography, SEM, TEM, EBSD
- Monotonic and cyclic stress-strain testing
- Thermocouples (standard and micro-arrays)
- Strain gauges, DIC, ESPI and hardness mapping

Modelling

- FE thermo-mechanical weld residual stress analysis
- 2D, 3D and moving heat source models
- Cyclic hardening and annealing
- Phase transformation effects
- Use of diverse FE codes
- Statistical analysis of measured data

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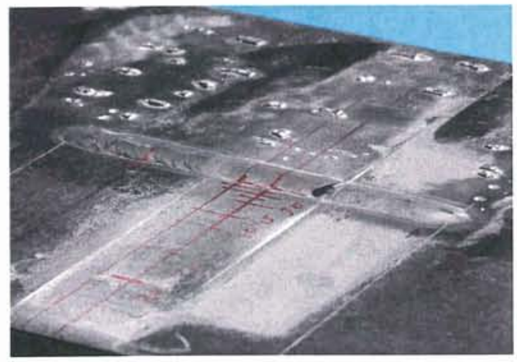
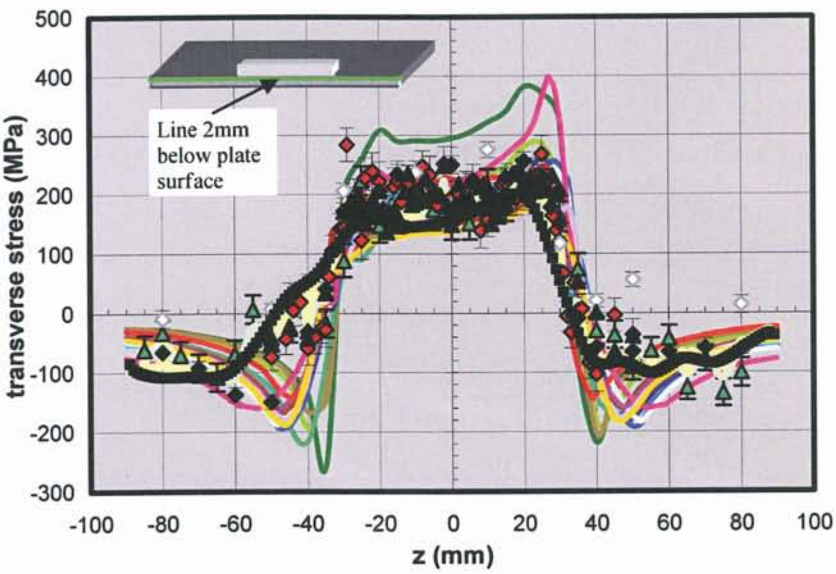
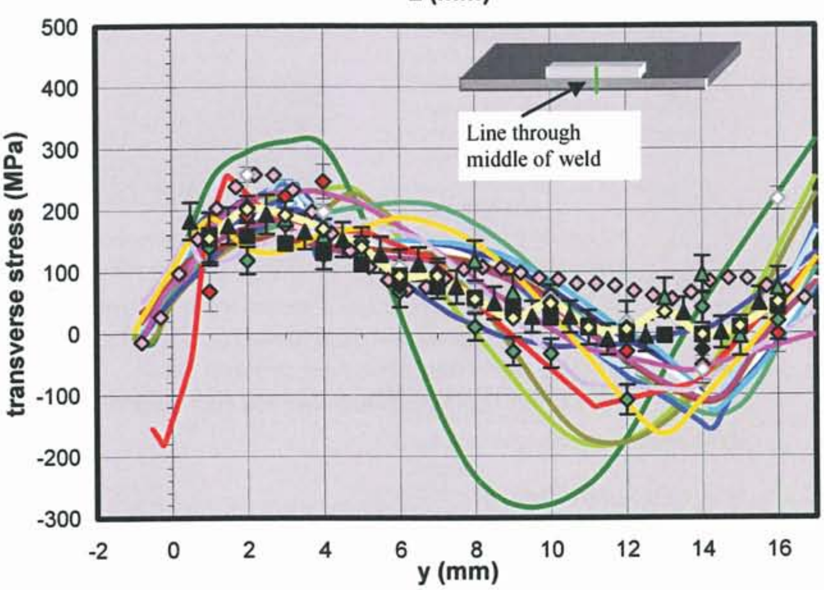
TG1: Single Bead-on-Plate Weldment (Stainless Steel)

Task Group 1 has studied the residual stress field around a short TIG weld bead deposited on the surface of a Type 316 austenitic stainless steel plate (180 × 120 × 17) mm^3 by conducting measurement and numerical round robins in parallel. This apparently simple geometry proved to be very challenging, both for experimentalists and analysts.

The numerical round robin was run in two phases:
- Phase 1 with unconstrained thermal efficiencies
- Phase 2 using a fixed 75% efficiency and advanced material hardening models







The figures show 18 FE predictions (solid lines) from 6 partners and 8 sets of measurements (symbols) including 6 neutron diffraction, deep hole drilling and contour method results; the upper graph gives transverse residual stress along a line 2mm below the plate surface and the lower shows the variation through the thickness at mid-length of the weld bead.

Lessons from TG1

- Measure the welding thermal efficiency
- Thermocouple all specimens
- Shield thermocouples against electrical interference from the welding torch
- Record temperatures at high enough frequency (>5 Hz)
- Make more use of strain gauges
- Specify measurement locations using prior knowledge of the global stress field
- Specify and control reference specimens
- Record what you measure and quantify measurement uncertainties
- The actual heat input must be modelled for this weld type
- Measure and model cyclic hardening behaviour of both the weld and parent materials for accurate stress predictions

Publication

A Special Issue of the International Journal of Pressure Vessels and Piping was published in January 2009 covering the Phase 1 results and their interpretation.

Benchmark

A weld residual stress simulation benchmark has been developed to accompany guidelines for calculating residual stresses in weldments that will be included in an update to the R6 defect assessment procedure in 2009.

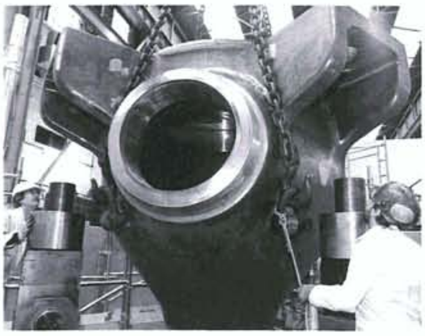
TG5: Edge Welded Beam (Ferritic Steel)

A ferritic steel (A508) beam $(180 \times 150 \times 10)\ mm^3$ with an autogenous weld along one edge is being studied by Task Group 5. This geometry and welding method avoids the addition of any (foreign) material to the system allowing analysts to concentrate on modelling phase transformations in the parent material. Early FE simulation work has shown that phase transformations are sensitive to the welding parameters, so one half of the test specimens have been welded at a 'slow' speed and the remainder at a 'fast' speed.

TG4: 3-Pass Slot Weld (Stainless Steel)

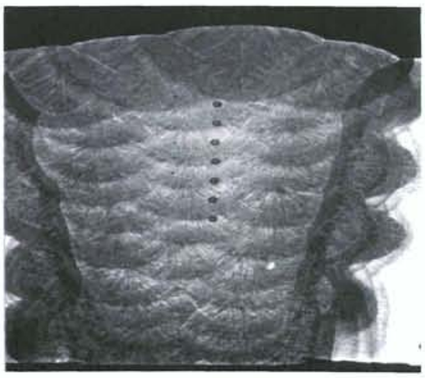
Task Group 4 was established late in 2007 to develop a 3-pass slot weld benchmark $(194 \times 150 \times 18)\ mm^3$ made from Type 316L stainless steel. This specimen geometry is more representative of engineering plant weld repairs than the TG1 bead-on-plate specimen. Measurement and FE simulation round robins will be carried out building on the lessons learnt in TG1 and TG2. The role of cyclic hardening in the evolution of residual stress in multi-pass stainless steel welds will provide a challenging focus for the new task group.

TG3: Thermal Ageing of Castings (Duplex Stainless Steel)



Small angle neutron scattering (SANS) facilitates the study of material heterogeneities by analyzing the scattering patterns of neutrons after passing through the specimen under investigation. Such analysis can give information about the size, shape and distribution of features such as voids and precipitates. TG3 employs SANS to investigate the effects of thermal ageing on cast duplex (austenitic-ferritic) stainless steels, which are used for some components of the primary loop of light water reactors. These steels are prone to thermal ageing at operating temperatures of around 300°C due to microstructural evolution of the ferritic phase.

TG2: Letter Box Repair Welds (Ferritic Steel)



Task Group 2 aimed to assess the impact of stress relieving heat treatments at different temperatures on the residual stress field around an 18-bead letterbox type repair weld in a 2.25CrMo ferritic steel plate $(200 \times 100 \times 20)\ mm^3$. However, these welds presented a huge challenge to modellers owing to the 3D nature of the problem, the large number of weld beads and the need to model phase transformation effects. Residual stress measurements on these specimens showed the effectiveness of even the lowest heat treatment regime at about 620°C.

TG2: Auxiliary Specimen (Ferritic Steel)

A more manageable 'auxiliary specimen' was manufactured with just three beads deposited in a slot within a 2.25CrMo ferritic steel plate $(400 \times 200 \times 20)\ mm^3$. Residual stress measurements have been obtained for this specimen using neutron diffraction and the contour method. Preliminary FE results have been obtained, and further work is being undertaken to incorporate phase transformation behaviour in the calculations.

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The NeT Journey

Micro-tensile weld specimens

NeT was established in 2002 by A. G. Youtsos who is the current chairman. Over 35 organisations from Europe and beyond are currently involved. NeT operates on a "contribution in kind" basis from industrial, academic and research facility partners.

The NeT partnership thrives on the synergy created by the need to reconcile predictions with measurements originating from diverse academic and industrial communities. This interdisciplinary interaction has stimulated new ideas, novel research studies, improved measurement practice, advances in residual stress prediction methods as well as a number of academic publications.

The network has adapted to long time-scales and recognised the need to ensure that new Task Groups have a committed long-term sponsor and dedicated resources to collate, understand and report results. On the practical side it has learnt about the importance of specimen manufacture (witnessing, photographs and recording), specimen tracking, the need for access to sufficient materials data and many measurement issues (for example, knowing the exact location of measurements).

Although NeT studies to date have been driven by the need to underwrite the safety and performance of critical welded or cast components in the nuclear industry, their outcomes have widespread industrial relevance.

Partners and Contributors to NeT

Coordinate measuring machine used for the contour method

New NeT partners are always welcome. If you are interested in participating, or for more information, please contact the Network Manager, Carsten Ohms, at the Joint Research Centre, email: Carsten.Ohms@jrc.nl, phone: +31-224-565012.

Australian Nuclear Science and Technology Organisation (ANSTO), Australia
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Institut National des Sciences Appliquées (INSA) Lyon, France
ISIS-Pulsed Neutron & Muon Source, Rutherford Appleton Laboratory, UK
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National Centre for Scientific Research "Demokritos", Greece
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