Measurement of Residual Stresses in a Dissimilar Metal Welded Pipe by Neutron Diffraction

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Introduction

Nickel-based weld filler materials are used to join ferritic and stainless steel components in the primary piping system of pressurized water reactors (PWRs) in nuclear power plants. Dissimilar metal weld (DMW) joints of this kind contain several material interfaces, involve multiple fabrication steps and often have a complex geometry. Stress corrosion cracking (SCC) has been observed at DMWs in many operating PWRs throughout the world. SCC is driven by the presence of tensile residual stress given a susceptible microstructure and adverse local chemistry. It is important to assess the distribution of residual stress in DMWs which is difficult to characterise with high certainty either by computational mechanics or measurement.

A new narrow-gap DMW using a corrosion resistant filler material (Alloy 52) has been designed by the French nuclear power plant constructor AREVA NP. A mock-up [designated (MC1)] of this new weld design has been fabricated and the residual stresses were measured by deep hole drilling (DHD) and by neutron diffraction using the high flux reactor at JRC-Petten [1] both before and after a post weld heat treatment (PWHT) at 600°C for 1h.

Here we report new neutron diffraction measurements made on mock-up MC1 after PWHT using ENGIN-X [2], the time-of-flight neutron diffraction facility at the ISIS Facility in the UK. In particular we focus on the strategy adopted to deal with the challenges of measuring this component including the section thickness (40 mm) and the issue of obtaining reliable stress-free reference measurements.

Results

Following Rietveld analysis [4] of the diffraction spectra, residual strains in three orthogonal directions were computed for the three measurement lines using the measured a, b, c values. Stresses were computed in the usual way assuming isotropic material behaviour and bulk elastic constants (E = 172 GPa and v = 0.29 for Alloy 52).

The distributions of residual stresses in three orthogonal along the centre-line of the Alloy 52 weld are shown in Figure 7. The largest tensile stress (264 MPa) was in the hoop direction close to the outer surface.

Methodology

Strain Scanning Simulation Software (SScanSS) [3] was used to design and control the experiment to high positional accuracy. Because the specimen thickness (40 mm) gave neutron path-lengths at the operational limit of the ENGIN-X diffractometer, non-standard neutron optics were used in order to increase the flux as illustrated in the Fig. 5. The penalty of increased beam divergence was minimised by placing the downstream slits as close as possible to the sample. A large gauge volume of 4×8×6 mm³ was used for the measurements to reduce the count time for the longest path-length to about 1 hour. The axial, radial and hoop strain components were measured at six points along three lines in four different materials as shown in Fig. 2. The worst spectrum for the longest path-length in the Alloy 52 material is shown in Fig. 6.

Conclusion

Residual stresses in a 40 mm thick dissimilar metal pipe weld have been successfully measured using the ENGIN-X instrument at the ISIS Facility. The measurements were achieved by opening the upstream slits to increase the neutron flux, using a large gauge volume and reducing the uncertainty in stress-free lattice parameter measurements by slowly spinning extracted cubes of welded materials. The origins of the large uncertainties in “unsusp” stress-free reference measurements are being investigated.

References

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