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Residual Stress

VEQTER is an engineering company providing excellence in the measurement, analysis and management of residual stresses. We are world leaders in our field and offer expertise on any aspect related to residual stresses in engineering components and structures.

Case Study: Safe-end Nozzle Dissimilar Metal Weld

Primary water stress corrosion cracking (PWSCC) is of great concern to the nuclear power industry having been the main failure mechanism for a number of integrity issues in recent years. For example: 1991 – PWSCC penetrated CRDM nozzle in Bugey Unit 3 (USA), 2000 – PWSCC found in the Hot-leg of Ringhals Units 3 & 4 (USA) and a similar metal weld of V.C. Summer (USA), and 2003 – cracking and leakage found in the safety and relief nozzles of Tsuruga Unit 2 (Japan). In order to evaluate the crack propagation of PWSCC in these types of components, it is essential to know the levels of residual stresses contained within the affected areas. Therefore, a large national project was carried out in Japan to improve the modelling techniques used for predicting residual stresses and crack growth. In order to test and verify the capabilities of the modelling techniques a number of component mock-ups were manufactured, modelled and measured for residual stresses.

This Case Study presents residual stress measurements carried out for this project on a Safe-End Nozzle Dissimilar Metal (DM) Weld using the Deep-Hole Drilling (DHD) technique. The DHD measurements were carried out on-site in Japan at differing stages of manufacture.

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Component Design:

The Safe-end Nozzle comprised of a ferritic steel nozzle with a tapered outer diameter attached to a stainless steel safe-end using a double-V, nickel base alloy weld with buttering layer. The main stainless steel coolant piping was then attached using a single-V stainless steel weld. The complete Safe-end Nozzle had a tapered outer diameter ranging from 883mm to 1192mm, an inner diameter of 735mm and an overall length of roughly 1680mm.

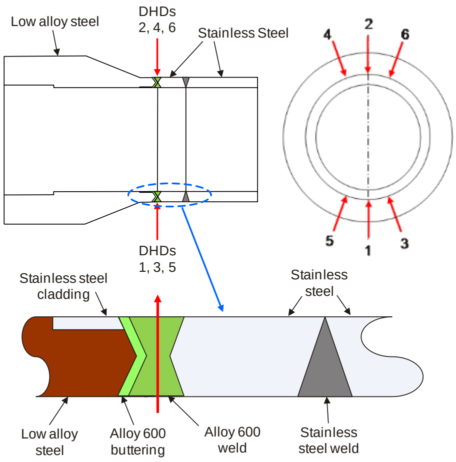

Fig. 1: Sketch of the Safe-End Nozzle with DHD locations identified

Measurements:

A total of 6 DHD measurements were carried out through the DM weld of the Safe-End Nozzle at different stages of manufacture, see Figure 2. All of the DHD measurements

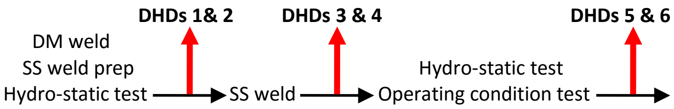

Fig. 2: Sequence of DHD measurements and manufacturing stages

were carried out through the centreline of the DM weld measuring the hoop and axial residual stresses as functions of radial depth, along with the associated shear stress. Residual stress measurements were also carried out by the client on an identical mock-up using the totally destructive Inherent Strain (IS) technique. The IS measurements were only carried out at a similar stage to DHDs 1 and 2.

Results and Discussion:

Figure 3 shows the hoop residual stresses measured and modelled after the initial stages of nozzle manufacture. It can be seen that there is excellent repeatability between the DHD measurements and excellent agreement between both measurement techniques and the finite element modelling.

Large tensile residual stresses were found at both the inner and outer surfaces of the DM weld with zero magnitude residual stresses at mid-thickness at the intersection of the double-V welds.

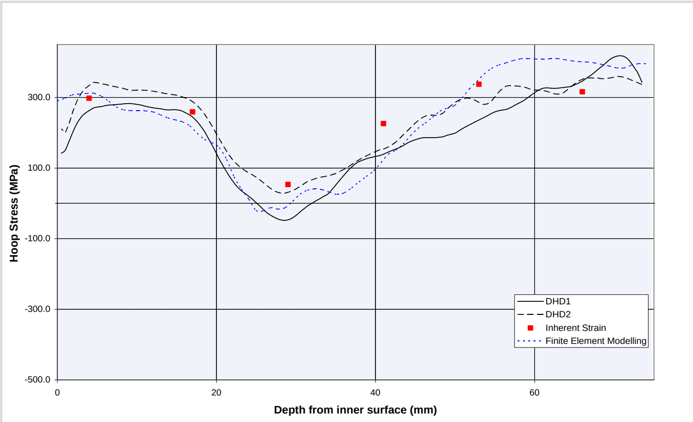

Fig. 3: Hoop residual stresses measured and modelled after the initial stages in manufacture

Figure 4 shows the changes in hoop residual stresses measured using the DHD technique at the different stages of manufacture.

It can be seen that the highest tensile stresses were measured in the as-welded condition (DHDs 1 & 2). Attachment of the main coolant piping with a stainless steel weld resulted in a large reduction in residual stresses, in particular towards the internal diameter where PWSCC would occur.

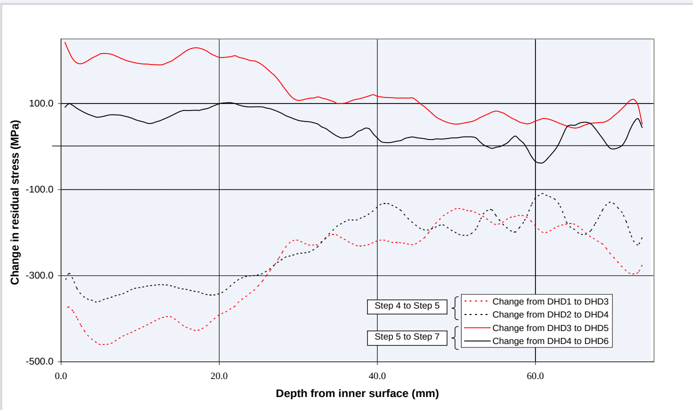

Fig. 4: Changes in hoop residual stresses during manufacture

Finally, the DHD measurements carried out after the second hydro-static test and the operating condition test (DHDs 5 & 6) showed increases in the hoop residual stresses. Overall, at the end of the manufacturing process, the axial residual stresses remained compressive at the inner diameter whereas the hoop stresses were approximately zero.

References: PVP2009-77830 and PVP2009-77269