FATIGUE CRACK GROWTH IN ELECTRON BEAM WELDMENTS

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Abstract

As the UK fleet of power plants changes technology from Advanced Gas Cooled Reactors to Light Water Reactors (LWR), the fatigue life of structural components in the primary coolant loop becomes of high interest. This is because of cyclic loading of LWRs caused by solid-liquid interactions which are less prominent in gas cooled reactors. Concurrently, modern welding techniques such as electron-beam (EB) welding are of great interest in LWR designs thanks to their benefits such as the ability to be automated, smaller heat affected zones and less material complexity as they can be deployed with no filler material (Horne et al., 2019). A common focus in studying weld fracture is the weld toe; this is because it has been observed that cracks often initiate in this region typically due to geometric effects and higher expected carbide deposition within the heat affected zone acting as stress concentrators. As EB welds have a very narrow heat affected zone and are automated, the expected region in which cracks may initiate, is less obvious. This work compares three crack initiation sites taken from a modern reactor material (stainless steel 316L) pipe containing a circumferential EB butt weld and evaluates the fatigue crack growth rate (FCGR) within the linear region of the Paris regime, to identify the region most susceptible to crack propagation.

Methodology

Stress-strain data across the weld line measured the properties of the pipe as a function of distance from the weld. This allowed the identification of the region of maximum yield strength (i.e. the most brittle zone). Compact tension (CT) specimens were cut from the weld line with notches cut in the weld longitudinal direction. Notch tips were located at three separate locations; the centre of the fusion zone, the fusion zone boundary, and the hard zone (Figure 1). The hard zone represents the region where both the maximum hoop stress and maximum yield strength occur.

FCGR tests are performed on each sample to ASTM E647-15$^{\varepsilon 1}$ specification. Fatigue pre-cracking is performed using a ΔK decreasing regime due to the large fracture toughness of 316L stainless steels causing issues with crack initiation when using smaller ΔK values, the ΔK values for fatigue pre-cracking were chosen to avoid any large plastic zones forming in front of the crack tip at the start of the FCGR tests. A ΔK incrasing regime using a constant load of ΔP=5kN is used for the FCGR tests giving an industrially relevant range of ΔK, 12 - 45 MPam$^{0.5}$. The tests are performed at 10Hz, with R=0.1. Both compliance and digital image correlation (DIC) data are collected. A finite element (FE) model is used to validate the ΔK value, along with the OUR-OMA

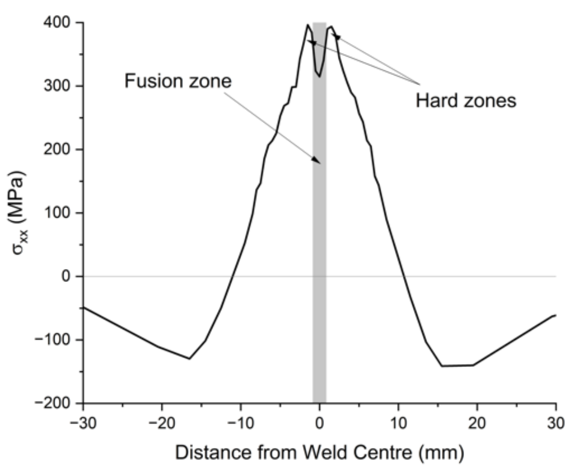

Figure 1 - Hoop residual stress in EB welded 316L pipe measured by synchrotron X-ray diffraction

(Barhli et al., 2017) code that converted data from the DIC to K values.

Discussion and conclusions

FCGR tests were performed on samples taken from three regions of an EB welded 316L stainless steel pipe. Crack growth rate data was compared between parent material and different positions of the weld. Parent samples showed strong agreement with the ASTM BPVC.XI reference curves, while measurements taken on the weld samples show decreased crack growth rates compared with the parent samples, the samples with notches cut at the fusion zone boundary and hard zone show similar decreases in crack growth rates.

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