Influence of Residual Stress on Fatigue Crack Growth of Ferritic Steel

Maliha Irfan

Department of Mechanical Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK

mi1125@ic.ac.uk

The pressurised water reactor (PWR) is contained in the reactor pressure vessel (RPV), which is commonly made from nuclear-grade low-alloy steel and produced by forging and subsequent welding. The performance and safe operability of RPVs are highly dependent on the integrity of their welded joints. During welding, rapid heating and cooling lead to microstructures that differ from those of the parent material and to the development of residual stresses. This raises a structural integrity issue for RPVs, as residual stresses could increase the driving force for surface defects to fracture while contributing to material degradation. The RPV has a typical design life of 40 years to ensure structural integrity throughout its service life [1]. Structural integrity assessments are carried out to rule out failure modes from postulated manufacturing defects. In PWR, most typical failure modes are non-ductile failure, plastic collapse and tearing instability. In the UK regulatory regime, it is required to demonstrate defect tolerance for high-integrity components such as RPVs; hence, it is necessary to demonstrate that fatigue crack growth from a postulated manufacturing defect is tolerable over the plant lifetime.

This proposed work aims to investigate and develop an improved method for predicting fatigue crack growth in A508 ferritic steel, accounting for residual stresses that are prevalent in PWR components. In the literature, fatigue crack growth in ferritic steel has been extensively investigated under various operating conditions, including crack growth rates at 1-100 Hz and load ratios of 0.1-0.7 [2,3,4], as shown in Figure 1. Residual stress in ferritic steel has also been investigated in the literature, as it undergoes solid-state phase transformations (SSPTs) during welding in the fusion and heat-affected zones; hence, FEA models have been developed to predict residual stress [5]. However, there is a lack of literature and research investigating the effect of residual stresses on fatigue crack growth.

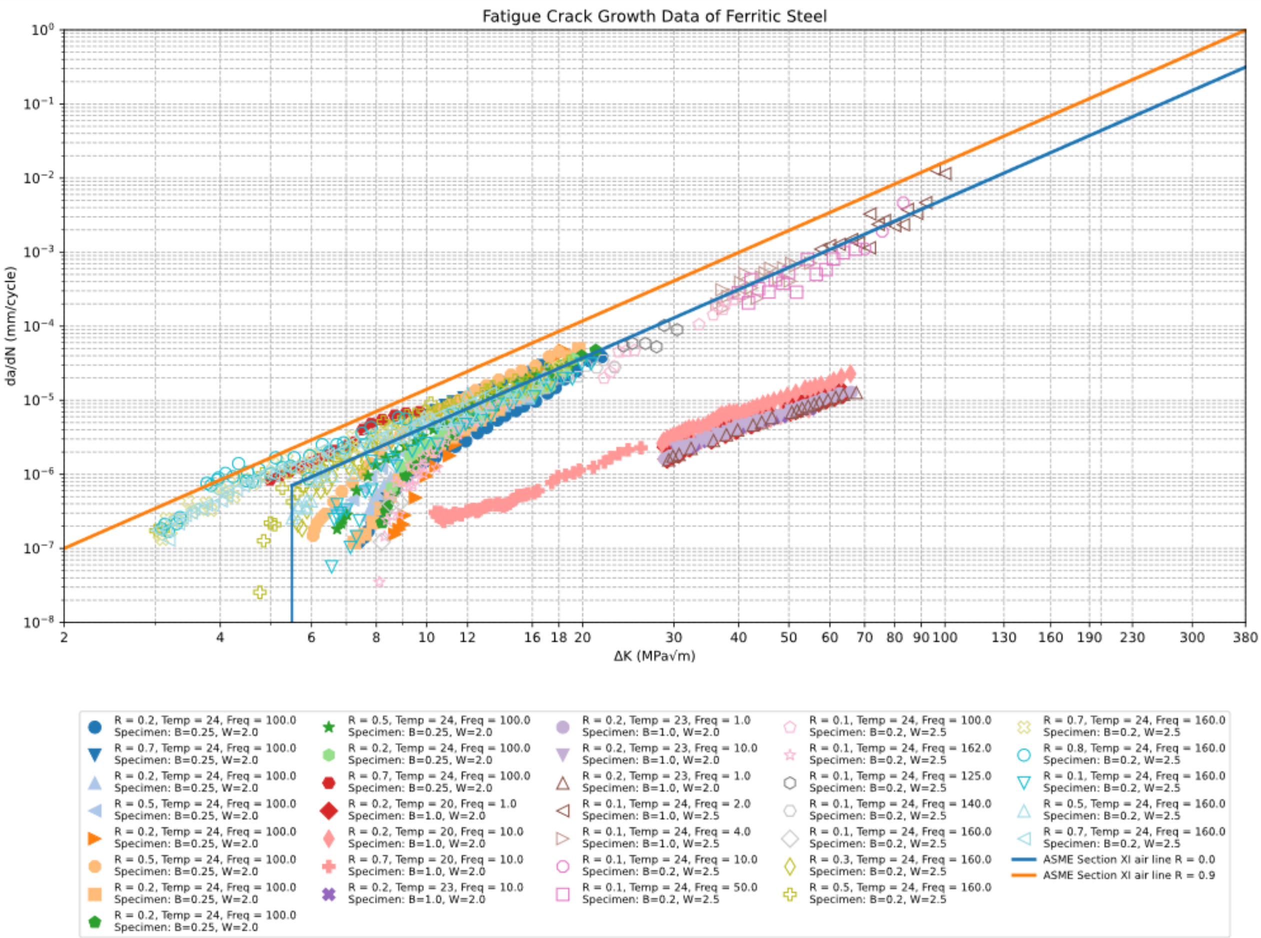

Figure 1 : Fatigue Crack Growth Data obtained from Literature [3,4,5]

To establish baseline Fatigue crack growth curves, the fatigue crack growth test will be conducted on a compact tension (C(T)) specimen geometry, 15 mm thick, made of SA-508 ferritic steel. To induce residual stress in a fracture mechanics test sample, Electron beam (EB) welding will be used, enabling the residual influence previously shown for creep crack growth [2]. The test will be conducted at a load ratio of 0.05 and 1 Hz for the base and welded samples. The result will be used to quantify the contribution of the crack-tip stress-intensity-factor parameter (K) due to residual stresses to fatigue crack growth during the tests. Finite element (FE) models are being developed to simulate the EB welding process using the methodology described in [6,7] and illustrated in Figure 2.

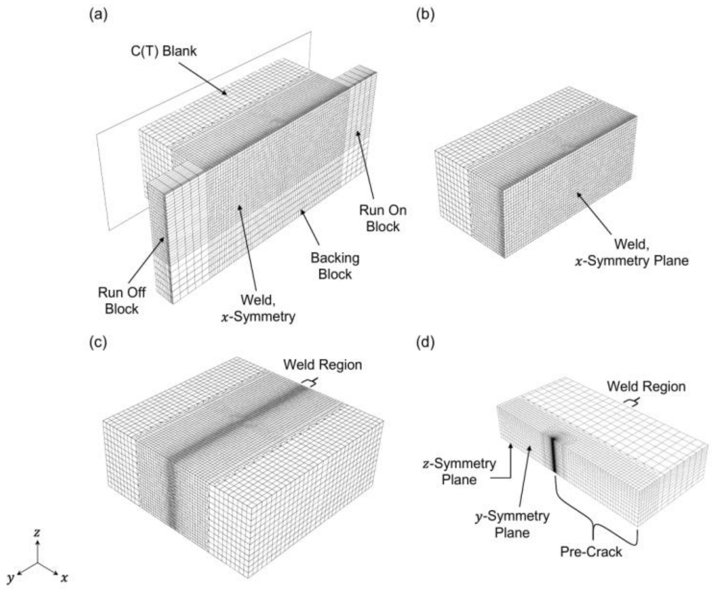

Figure 2 : Mechanical models used to simulate fabrication of the EB-welded C(T) specimen [3]

Conclusion

This work forms part of a PhD research project part sponsored by EDF Energy UK and EPSRC entitled 'Improved Methods for Predicting Fatigue Crack Growth Behaviour in PWR Components: Fatigue Crack Growth for Complex Loading Histories that Include a Contribution from Welding Residual Stresses'. The outcomes will be used to develop the UK nuclear codes for plant lifetime assessment.

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