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Application of hysteresis energy criterion in a microstructure-based model for fatigue crack initiation and evolution in austenitic stainless steel

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Abstract

The Sistaninia-Niffenegger Fatigue (SNF) model, a mesoscale hysteresis energy-based model of fatigue crack initiation, is calibrated and validated both by experiments and numerical modeling. The simulations are able to reproduce the fatigue life curves for the AISI 316L austenitic stainless steel of different grain sizes. In addition, it's shown that the model captures the crack initiation site and the subsequent propagation through the anisotropic microstructure in a real multi-notched sample subjected to high cycle fatigue (HCF) loading. The microstructure of the polycrystal is determined by electron back scattering diffraction (EBSD), whereas the material properties of the polycrystal and the parameters of the model are obtained by inverse analysis using the Levenberg-Marquardt algorithm, based on the tensile stress-strain curves and the HCF test results, respectively. The model can be applied to different microstructures under HCF loading and evaluate crack initiation and its evolution with precision within the intrinsic scattering of HCF tests.

Keywords: Fatigue crack initiation and growth, High cycle fatigue, Microstructure-based numerical modeling, Hall-Petch relation, Single crystal properties

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1. Introduction

Turbulent mixing of hot and cold water often causes cyclic thermal shocks in the primary circuit piping of light water reactors (LWRs) leading to thermo-mechanical fatigue (TMF). Due to its relevance, this phenomenon has been widely investigated [1, 2, 3], although the exact conditions which lead to TMF and the associated development of crack networks (crazing), as found in mixing tees of LWRs [4, 5, 6], are not yet fully understood and more research is needed.

Most of fatigue cracks are initiated at microstructure level due to the irreversible plastic deformation accommodated in the grains of the material [7, 8], and thus taking into account of the microstructure is vital to address the material behavior successfully.

The fatigue process can be divided into two or three stages [9, 10]. After microcracks initiate, they grow from short to long cracks, which may result in failure of the component. Crack initiation can have different causes, as initial defects and discontinuities [8, 11], or others linked to the microstructure (grain boundaries, slip bands) [7, 8, 12] . Some researchers estimated that the duration of short crack growth in high cycle fatigue was about 50-70% of the total fatigue life [13]. Others like Suresh et al. [7], affirmed that 90% of the fatigue lifetime was spent during the growth of a dominant crack. This reinforces the important role that microstructure plays during the fatigue process. However, empirical approaches for fatigue life determination like the Basquin and Manson-Coffin relations [14, 15], are not considering the microstructure but are useful for the engineering assessment of components.

Microstructure-based models account for the anisotropic grain behavior. Among this group are the dislocation theory-based models, like Tanaka and Mura [16] and the **F**atigue **I**ndicator **P**arameters (FIP)-based ones [17, 18, 19]. The former uses a dislocation pile-up model to obtain the number of cycles to crack initiation from the local plastic shear amplitude. The latter group can pre-

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