
Multi-Scale Characterization and Modelling of the Deformation Behavior in an Aged Duplex Stainless Steel

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Abstract

Duplex stainless steels (DSSs), composed of austenitic and ferritic phases, are used in nuclear power plant components. Before service, they are subjected to long-term thermal aging, which results in the spinoidal decomposition of the ferritic phase into Cr-rich and Cr-poor regions and leads to the strengthening of the decomposed ferrite and alloy. An in-depth understanding of the microstructure-mechanical behavior relationship of the steel after aging is still lacking and deserves further investigation. In this work, a three-scale (nano-micro-meso) approach is proposed to study the mechanical behavior of the DSS at room temperature. At the mesoscopic scale, polycrystalline representative volume elements (RVEs) of homogenised austenitic grains with approx. 9.5% embedded (coherent) ferrite islands are constructed from EBSD orientation maps to formulate and calibrate the homogenized single crystal grain behaviour before and after ageing from uniaxial stress-strain responses of the DSS. Micro-scale RVEs, which consist of an austenitic single crystal grain with embedded coherent as-received (AR) and aged ferritic phase islands, are relied upon to develop and calibrate constitutive models for the AR and aged ferrite, based on the homogenized RVE response identified at the meso-scale and the austenite behaviour determined from an austenitic stainless steel. At the nano-scale, a phase field model is relied upon to predict the formation of Cr-rich and Cr-poor regions due to the spinodal decomposition of the ferrite. The resulting phase field predictions are then used to construct nanoscale RVEs of the spinodally decomposed ferritic phase (with an approx. 26% vol. fraction) to formulate and calibrate the single crystal behaviour of the Cr-rich phase, assuming that the Cr-poor phase behaves like undecomposed ferrite, with the nano-scale RVE behaviour given by the ferrite response identified at the micro-scale. Based on these results, an isotropic elasto-visco-plastic constitutive model for the DSS is proposed at the macro-scale and validated experimentally. The proposed multi-scale modelling approach is shown to satisfactorily capture the evolution of the microstructure and stress-strain behaviour of the DSS as a function of ageing conditions. Furthermore, localisation of inelastic strain at different scales are predicted, and the effect of ageing time identified, providing a mechanistic basis to tailor ageing treatments for optimum service behaviour. Ongoing work extends this approach to temperatures typical of service in the 280-320oC range.

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