Nonlinear Constitutive Modelling of Plastic Strain-Induced Martensitic Transformation in Austenitic Stainless Steels at Cryogenic Temperatures

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ABSTRACT

Austenitic nitrogen-strengthened stainless steels are commonly used to manufacture structural components in high-field superconducting magnets systems due to their stable material properties over the whole temperature operating range of the magnets. They retain high strength, ductility and toughness at low temperatures and are paramagnetic or antiferromagnetic under the Néel temperature in their fully austenitic state. However, they are susceptible to strain-induced martensitic transformation at cryogenic temperatures, generating martensite phase embedded into the austenitic matrix. This transformation modifies the material properties, induces change of volume and additional strain hardening, and might lead to a ferromagnetic behaviour. The influence of this transformation on the fatigue behaviour of these structural components is of great interest since the magnets are submitted to a high number of stress cycles during operation. Therefore, an adequate constitutive modelling of these materials at very low temperatures is essential. In the present work, we propose a mixed kinematic-isotropic nonlinear hardening model valid at large strains, which includes the effects of the strain-induced martensitic transformation. The kinematic contribution is implemented using the Armstrong-Frederick model, and an equivalent exponential hardening law is used to model the isotropic hardening. Moreover, the strain-induced martensite transformation is modelled by a nonlinear kinetic law. Based on the above modelling, the fatigue behaviour of austenitic stainless steels at cryogenic temperatures has been numerically computed and verified using experimental data. The model is being further developed to account for the prediction of the fatigue crack growth rate and fracture toughness of these materials at cryogenic applications.