Analysis of a Steam Turbine Rotor with a Composite Model for Rate-Dependent Inelasticity

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ABSTRACT

Components in power plants are subjected to elevated temperatures over long holding times. Furthermore, in order to account for the intermittent energy production of renewable sources, power plants are often started and shut-down, which induces creep-fatigue loads. Since heat-resistant steals feature excellent thermo-mechanical properties, e.g. high tensile strength and elevated corrosion resistance, these alloys are commonly used for power plant components. However, these steels exhibit a major drawback because they tend to soften under deformation.

The current contribution presents the simulation results of a thermo-mechanical analysis of a steam turbine rotor made of a heat-resistant steels. To describe the constitutive behavior, a unified composite model is introduced, incorporating both rate-dependent inelasticity, hardening, as well as softening. The model employs a micro-mechanical iso-strain approach with a soft and a hard constituent. Whereas the soft constituent comprises regions with low dislocation density, the hard constituent describes areas with high dislocation density. The introduction of two internal variables (a backstress tensor of Armstrong-Frederick type and a softening variable) results in a coupled system of three evolution equations.

The constitutive model is implemented into the FEM based on implicit time integration of the evolution equations to enable the in-service assessment of a steam turbine rotor. The conducted thermo-mechanical analysis accounts for the complex geometry as well as realistic boundary conditions. First, the temperature field in the rotor is obtained during a heat transfer analysis, whereas instationary and inhomogeneous steam temperatures and heat transfer coefficients are prescribed. The resulting temperature distribution serves as input for the subsequent structural analysis based on the composite model. Note that the influence of different start-up procedures is analysed. Furthermore, we examine the numerical performance of the implemented constitutive model and the computational costs to simulate the influence of loading cycles on the rotor in detail.