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Constitutive Modeling of Tempered Martensitic Steels at Elevated Temperatures

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Tempered martensitic steels are established materials for power plant components. Due to frequent start and stop operations of power plants operating at high temperatures, the components are subjected to creep-fatigue loads. Although these alloys offer superior mechanical and thermal properties, it is well known that they suffer from softening effects under constant and cyclic loads. To describe the complex mechanical behavior, this contribution employs a composite model, which makes use of an iso-strain approach including two constituents. The hard constituent is related to areas with a high dislocation density, while the soft constituents represents regions with a low dislocation density. The introduction of two internal variables (Armstrong-Frederick-type backstress and a softening variable) allows for a robust and unified description of rate-dependent inelasticity, hardening, and softening. Note that the model is calibrated based on macroscopic tests and implemented into the finite element method using implicit time integration.

In order to demonstrate the applicability of the implemented constitutive model, a thermo-mechanical analysis of a steam turbine rotor is conducted, while accounting for the complex in-service boundary conditions. Within the preceding heat transfer analysis, instationary steam temperatures and heat transfer coefficients are prescribed, and the temperature distribution in the rotor is computed. The obtained temperature field serves as input for the subsequent structural analysis with the implemented constitutive model. Thereby, the influence of different start-up procedures (hot and cold starts) as well as the cyclic behavior of the rotor are examined in detail. Furthermore, the required computational effort and the numerical performance of the implemented model are discussed. For future applications, these results could lay the foundation for the estimation of creep and fatigue damage, thus allowing for a precise prediction of the lifetime of power plant components in use.