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A constitutive model for rate dependent and rate independent inelasticity. Application to IN718

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ABSTRACT

In this paper, a constitutive model for the unified description of rate dependent and rate independent material behavior is proposed. It is applicable to isotropic metals subjected to arbitrary thermomechanical loading conditions at small strains. The focus of the model formulation is its validity for the full range of thermal and mechanical loading conditions to be covered in an industrial context by e.g. modern aero-engine designs. Consequently, the proposed model describes the material behavior on a macroscopic level covering the full temperature range from room temperature to the upper application limit under monotonic as well as cyclic loading. Special emphasis is also put on the correct representation of the observed ratcheting behavior. The most prominent features of the model are the combined treatment of both, rate dependent, as well as rate independent inelasticity through a limit surface concept, the description of primary, secondary and tertiary creep behavior and the application of an appropriate backstress evolution equation. A fully implicit integration algorithm for the proposed model is developed and implemented in connection with uniaxial integration point drivers as well as three alternative Finite Element packages. The parameters of the proposed model can be identified based on a limited number of complex cyclic tests and monotonic creep tests. After reporting on the fitting results for such tests for the Nickel-base superalloy IN718 the predictive capabilities of the proposed model are assessed for a number of isothermal and nonisothermal tests. Finally, the performance of the algorithmic implementation into the Finite Element packages is briefly addressed.

1. Introduction

In view of more efficient designs of structural components, the material capability in withstanding various loading regimes is exploited further and further. Thus, in order to allow for lighter designs at ever increasing temperature and/or load levels, material scientists eagerly develop high-end superalloys with improved capabilities. However, in order to safely profit from these capabilities during the design phase as well as to allow for an exploitation of the entire potential of already existing alloys it is at least of the same importance to enable a precise and efficient description of the material response within the relevant loading regime.

Therefore, the scope of this paper is the proposal of a constitutive material model allowing for an efficient application throughout the design of structural components of e.g. modern aero-engines. Many constitutive material models for the description of cyclic inelasticity have been proposed in the literature over the past few decades (Armstrong and Frederick, 1966; Mróz, 1967; Bodner, 1987; Contesti and Cailletaud, 1989; Nouailhas, 1989; Chaboche et al., 1991; Freed and Walker, 1993; Ohno and Wang, 1993; Chaboche, 1991; Chaboche, 1994; Jiang and Sehitoglu, 1996; Auricchio, 1997; Ohno, 1998;

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