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On backstresses, overstresses, and internal stresses represented on the mesoscale

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Abstract

The notions 'backstress', 'effective stress', 'overstress' and 'equilibrium stress' are given clear physical meaning by confronting their use with the use of internal stresses represented on the mesoscale as tensorial internal variables. Our way of modeling creep and relaxation is newly presented and agreement with experimental findings demonstrated. It is shown that in the case of a monotonic uniaxial deviatoric loading, the relation of the macroscopic stress to the 'backstress' or 'equilibrium stress' equals the relation of the acting force to that part of this force that is sustained by the infrastructure of barriers that do not undergo plastic deformation or rheological flow.

Keywords: Mesomechanics; Backstresses; Effective stress; Overstresses; Equilibrium stress

1. Introduction

It is well known that the simple classical relations of incremental plasticity and of rheology – that assume linear relation between the rate of deviatoric strain and the

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deviatoric macroscopic stress – do not describe the real behavior of materials under complicated loading paths. To overcome this drawback, the quantities called 'backstress' in plasticity and 'overstress' in rheology have been introduced by some authors. Thus, Voyiadjis and Kattan (1991) used backstresses in their formulation of a constitutive model with kinematic hardening. They introduced two backstresses with independent evolution rules. In the resulting constitutive model the stress evolution turns out to be independent of the stress rate. Voyiadjis and Huang (1996) applied the concept of backstresses to two-dimensional crystal plasticity to show the possibility of modeling isotropic hardening, kinematic hardening and crystal orientation. Aktaa and Schinke (1997) introduced backstress as an internal variable characterizing the damage rate in their time dependent damage model that takes into account the dependence of damage evolution at high temperatures on the deformation history. Voyiadjis and Basuroychowdhury (1998) and Basuroychowdhury and Voyiadjis (1998) studied cyclic plasticity for multiaxial loading, ratcheting and non-proportional loading. They used specific backstress evolution equations governed by the deviatoric stress rate direction, the plastic strain rate, the backstress, and the proximity of the yield surface from the bounding surface. Bari and Hassan (2000) critically evaluate the performance of five constitutive models in predicting ratcheting responses. Their study indicates a strong influence of the kinematic hardening rule or backstress direction on multiaxial ratcheting simulation. Improvements can be achieved by the incorporation of parameters dependent on multiaxial ratcheting responses, or uncoupling of the kinematic hardening rule from the plastic modulus calculation, or the incorporation of yield surface shape change in the cyclic plasticity model. El-Magd and Kranz (2000) studied internal backstresses under creep load. With evolution equations considering microstructural changes they described the evolution of internal backstresses in the primary creep stage and the stress dependency of the stationary value in the secondary creep stage. Almroth et al. (2002) used backstress as state variable in modeling of the high temperature behaviour of IN792. Antretter et al. (2002) in their extensive experimental program on steel showed that for explaining the observed phenomena it was necessary to assume the existence of backstresses in the initial state – backstresses in the same order of magnitude as the load stress. It is especially in connection with these observations that the question of the physical nature of backstresses pregnantly arises, as backstresses – not being self-equilibrated – cannot be internal stresses. Voyiadjis and Abu Al-Rub (2003) use the thermodynamic nomenclature for the formulation of a nonlinear kinematic hardening rule. The application of the laws of thermodynamics to solids is of course far from being as straightforward as the application to liquids because of the existing internal residual energy that is changed with inelastic deformation. In phenomenological models, this problem is bypassed by finding such internal variables as to fit experimental findings. Proceeding in this way, a combined form of the backstress evolution equation was chosen such that the motion of the center of the yield surface in the stress space is directed between the gradient to the surface at the stress point and the stress rate direction at that point. Böhlke et al. (2003) emphasize the difference of the Cauchy stress and the backstress. Hsu and Lin (2003), in their analysis of Ni–Cu–P deposit on Al, work with internal stresses, but the internal