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An alternative to kinematic hardening in classical plasticity

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ABSTRACT

In this work, an approach is proposed for the description of the plastic behavior of materials subjected to multiple or continuous strain path changes. In particular, although it is not formulated with a kinematic hardening rule, it provides a reasonable description of the Bauschinger effect when loading is reversed. This description of anisotropic hardening is based on homogeneous yield functions/plastic potentials combining a stable, isotropic hardening-type, component and a fluctuating component. The latter captures, in average, the effect of dislocation interactions during strain path changes. For monotonic loading, this approach is identical to isotropic hardening, with an expanding isotropic or anisotropic yield surface around the active stress state. The capability of this constitutive description is illustrated with applications on a number of materials, namely, low carbon, dual phase and ferritic stainless steel samples.

1. Introduction

In metal forming, numerical simulations are very useful to optimize processes, and thereby, decrease development time and cost. Accurate results are achievable if sufficient consideration is paid to the choice of the numerical parameters, including type of mesh, boundary conditions and material constitutive behavior. The latter, in particular the plastic behavior, is the topic of this paper. In plasticity, multi-scale modeling has been instrumental for understanding the relationship between macroscopic properties and microstructural features at different scales and has been successfully applied for material design (McDowell, 2010). Philosophically, multi-scale is a very comprehensive and interpretive approach to constitutive modeling. However, in many instances, it does not address very well the practical manufacturing needs, e.g., in the sheet forming industry when simple, yet accurate, material models with time-efficient implementations in commercial finite element (FE) codes are required. This is a domain where continuum descriptions are still very powerful.

Plasticity in metals is a phenomenon that is mainly controlled by dislocation glide on slip systems occupying weak or strong preferred orientations. The fields of dislocations dynamics and crystal plasticity have been very active over many decades to qualitatively and quantitatively understand the numerous mechanisms occurring during plastic deformation. The effects of crystal plasticity have been roughly captured at the continuum level by the introduction of non-quadratic yield functions/plastic potentials (Hershey, 1954; Hosford, 1985; Barlat and Lian, 1989). These functions have been employed successfully in a number of examples where loading is nearly proportional (for instance, Yoon et al., 2004, 2006). However, this is no longer the case when a material is subjected to cross-loading or stress reversal.

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