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On the numerical implementation of thermomechanically coupled distortional hardening

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Abstract

In contrast to the by now classic isotropic and kinematic hardening, the more general framework of distortional hardening characterised by an evolution of the yield surface's shape can capture the effect of texture evolution on the macroscopic response. Although different distortional hardening models can indeed be found in the literature, efficient numerical implementations of such models are still missing. This statement proves particularly true within a thermomechanically coupled framework which is important for most technologically relevant processes – such as for deep drawing. Accordingly, this paper deals with an efficient finite element formulation for distortional hardening within a thermomechanically coupled framework. As a first step towards this target, the recently advocated isothermal distortional hardening framework Shi et al. (2014) is extended to the thermomechanically coupled setting. In order to avoid an over-estimation of the temperature increase due to plastic deformation, the initial yield stress is decomposed into a classic dissipative part and a non-classic energetic part. By doing so, the restrictions imposed by thermodynamical principles are fulfilled and simultaneously realistic temperature predictions are obtained. For the resulting model, an efficient numerical implementation is proposed. By developing a suitable time integration scheme for the evolution equations of the fourth-order tensor describing the distortional hardening, a return-mapping scheme for updating the internal variables is derived which shows the same numerical complexity as a return-mapping scheme for purely isotropic hardening. This efficient return-mapping scheme is finally incorporated into a thermomechanically coupled finite element formulation, and the resulting set of equations is fully implicitly and monolithically solved by means of a Newton-type iteration. Several numerical complex examples demonstrate the capabilities of the distortional hardening model as well as the robustness and efficiency of the numerical formulation.

Keywords: Thermomechanical coupling; Distortional hardening; Temperature prediction; Efficient numerical implementation;

1. Introduction

Thermomechanically coupled finite strain elastoplasticity is relevant in many technological forming processes. As far as metallic alloys are concerned, typical examples are deep drawing or extrusion. Although these two representative forming processes are indeed significantly different from each other, they do share some common features. From a metal physics point of view, an important common feature is the evolving plastic anisotropy of the considered alloys due to texture evolution. The description of this anisotropy within a thermomechanically coupled setting is precisely one focus of this paper. Since the physical description of an evolving anisotropy within a thermomechanically coupled setting leads to rather complex constitutive models and furthermore, the boundary value problems approximating forming processes are also complex by themselves, the numerical formulation of the resulting overall model is not straightforward and special care is required with respect to the numerical robustness and numerical efficiency. This is precisely the second focus of the paper: the elaboration of an efficient finite element implementation accounting for anisotropic plasticity-induced hardening within a thermomechanically coupled setting.

The evolving plastic anisotropy of alloys due to texture evolution can be described by means of different models. Focusing on continuum mechanics, possible options are crystal plasticity (Kalidindi and Anand, 1992; Staroselsky and Anand, 2003; Agnew and Duygulu, 2005; Homayonifar and Mosler, 2012) or purely macroscopic theories (Baltov and Sawczuk, 1965; Backhaus, 1968; Lehmann, 1972; Ortiz and Popov, 1983; Feigenbaum and Dafalias, 2007). The major advantage of crystal plasticity theory is that the most relevant phenomena at the microscale, such as plastic slip at individual slip planes, can naturally be included in the considered constitutive framework. However, if macroscopic problems are to be analysed like those relevant in forming

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