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On the coupling of plastic slip and deformation-induced twinning in magnesium: A variationally consistent approach based on energy minimization

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ABSTRACT

The present paper is concerned with the analysis of the deformation systems in single crystal magnesium at the micro-scale and with the resulting texture evolution in a polycrystal representing the macroscopic mechanical response. For that purpose, a variationally consistent approach based on energy minimization is proposed. It is suitable for the modeling of crystal plasticity at finite strains including the phase transition associated with deformation-induced twinning. The method relies strongly on the variational structure of crystal plasticity theory, i.e., an incremental minimization principle can be derived which allows to determine the unknown slip rates by computing the stationarity conditions of a (pseudo) potential. Phase transition associated with twinning is modeled in a similar fashion. More precisely, a solid–solid phase transition corresponding to twinning is assumed, if this is energetically favorable. Mathematically speaking, the aforementioned transition can be interpreted as a certain rank-one convexification. Since such a scheme is computationally very expensive and thus, it cannot be applied to the analysis of a polycrystal, a computationally more efficient approximation is elaborated. Within this approximation, the deformation induced by twinning is decomposed into the reorientation of the crystal lattice and simple shear. The latter is assumed to be governed by means of a standard Schmid-type plasticity law (pseudo-dislocation), while the reorientation of the crystal lattice is considered, when the respective plastic shear strain reaches a certain threshold value. The underlying idea is in line with experimental observations, where dislocation slip within the twinned domain is most frequently seen, if the twin laminate reaches a critical volume. The resulting model predicts a stress–strain response in good agreement with that of a rank-one convexification method, while showing the same numerical efficiency as a classical Taylor-type approximation. Consequently, it combines the advantages of both limiting cases. The model is calibrated for single crystal magnesium by means of the channel die test and finally applied to the analysis of texture evolution in a polycrystal. Comparisons of the predicted numerical results to their experimental counterparts show that the novel model is able to capture the characteristic mechanical response of magnesium very well.

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1. Introduction

Light-weight materials are of great importance in transportation industries. Very promising candidates are magnesium and its alloys. Due to their high specific strength and their relatively low cost, they challenge aluminum alloys in some

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