Phase-field modelling of twinning in magnesium: microstructure evolution and size effects in nano-indentation

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Abstract

Plastic slip in magnesium and its alloys is accompanied by deformation twinning which is an important deformation mechanism due to the lack of easily-activated slip systems. Twinning is associated with microstructure evolution, including nucleation, propagation and annihilation of twin boundaries, which significantly impacts the plastic slip due to the lattice rotation induced by twinning. To model the related phenomena, we have developed a finite-strain phase-field model of deformation twinning coupled with crystal plasticity. In contrast to the common approach, twinning is treated as a volume-preserving stretch so that a single order parameter can be used to describe two conjugate twinning systems. Our finite-element implementation relies on the micromorphic approach so that the complex constitutive equations of crystal plasticity can be effectively included in the phase-field framework. We have recently extended the model by incorporating a simple description of slip-gradient effects. As a result, the model is capable of describing size effects introduced by the interfacial energy of twin boundaries within the phase-field framework and by the slip-gradient effects within the gradient crystal plasticity. The related effects are illustrated by modelling the nano-indentation of a magnesium single crystal. We show that the interfacial energy governs the microstructure, i.e., the morphology of twins, while its impact on the mechanical response is limited. Opposite dependencies are observed in the case of slip-gradient effects.

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