Phase-Field Model for Spatially Resolved Deformation Twinning Coupled with Crystal Plasticity

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Deformation twinning is classically treated as a simple shear that occurs on well-defined crystallographic twinning systems. Here we propose to treat twinning as a displacive transformation, resembling a phase transformation, such that the transformation from the parent matrix to a twin deformation variant occurs through a stretch followed by a rotation. The respective finite-deformation kinematics is then introduced in the sharp- and diffuse-interface frameworks and includes a consistent description of twinning-induced reorientation of crystal lattice and slip systems. This kinematics is also a convenient framework for developing a phase-field model of coupled twinning and crystal plasticity. The phase-field model is developed within the incremental energy minimization approach. The resulting incremental minimization problem is non-smooth due to the rate-independent dissipation terms and bound constraints enforced on the order parameter describing the diffuse twin boundaries. A micromorphic regularization is thus applied to facilitate finite-element implementation of the model, in particular, to efficiently treat the non-smooth terms in the incremental potential. Spatially resolved evolution of twin microstructure is studied for an HCP magnesium alloy, for which a two-dimensional computational model is developed that includes one twin deformation variant, i.e., two conjugate twining systems, and three effective slip systems (one basal and two pyramidal slip systems).