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Multiphase-field method accounting for crystal plasticity

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In the context of classical continuum mechanics, several plasticity theories are well established since decades, e.g., the Mises plasticity [1], crystal plasticity (CP)[2], and, (slip) gradient plasticity. While the Mises plasticity represents a phenomenological plasticity theory, CP theories are mechanism based theories. Regarding single, oligo- or polycrystals, they take into account the underlying crystalline microstructure such as the crystal lattice, and, thus, the slip systems, characteristic of a particular crystal symmetry such as face centered cubic (FCC) crystals. Moreover they account for the orientation of the lattice and can, therefore, be used to reproduce plastic anisotropy based on the activated slip systems. In CP theories, the evolution of the plastic slip is closely related to the evolution of the dislocation density by the Kocks–Mecking law. Hence, the plastic slip is commonly considered as an internal state variable in an approximate sense. The evolution equations for the plastic slips are, thus, both thermodynamically consistent and based on the mechanisms of lower scales, representing them in an averaged, coarse-grained sense. Regarding classical continuum mechanics, grain boundaries (GBs) between adjacent grains are commonly modeled as material singular surfaces [3]. From a numerical poin of view, the tracking of GBs during a deformation can be expensive, regarding a polycrystal. To circumvent this drawback, the combination of the CP theory with the multiphase-field method (MPFM) is presented. Within the MPFM, GBs are regularized and represented by interphases of finite thickness for numerical treatment. The incorporation of the CP theory in the context of MPFM is briefly adressed. The application of the presented framework to bicrystals illustrates the relationship and differences with a classical treatment of GBs as singular surfaces.

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