Finite Element Modeling of Deformation Bands in Single-Crystal Plasticity at Small Strain

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Abstract

The non-uniqueness of solutions in rate-independent crystal plasticity represents a fundamental challenge in modeling plastic deformation. A key difficulty arises at the material point level, where the determination of active slip systems is complicated by the indefiniteness of the slip-system interaction matrix. A computational framework based on incremental energy minimization provides an effective approach to resolving this ambiguity, yielding solutions that capture the underlying physical mechanisms without relying on artificial regularization techniques.
In this work, we investigate the spontaneous formation of deformation bands in plastically deforming single-crystal metals. Incremental energy is formulated at the Gauss-point level, and a trust-region algorithm is employed to minimize the non-convex energy functional and identify the increments of active slip systems, which are not predefined. The analysis is conducted within the small-strain crystal plasticity framework.

Our study reveals that, under specific conditions, the material develops a characteristic laminate structure, often referred to as a zig-zag pattern. Finite element simulations under plane-strain conditions demonstrate the spontaneous emergence of deformation bands, highlighting the critical role of the yield-vertex effect. These simulations capture the alternating deformation patterns caused by latent hardening, providing direct numerical evidence of this phenomenon. Notably, the algorithm avoids any reliance on predefined band structures or explicit lamination, ensuring that the observed banding arises naturally from the governing equations and imposed boundary conditions.

References

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