A reduced micromorphic single crystal plasticity model at finite deformations

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Strain localization is commonly encountered in experiments involving a wide range of materials at scales spanning over multiple orders of magnitude. Mechanical instabilities involving either geometric or material imperfections are prequels to strain localization. In metals, a porosity growth induced softening may lead to a material-based instability called shear-banding, while necking in a tensile test is an example of a geometry-based instability. In single crystals slip bands and kink bands are common occurrences of material induced strain localization phenomena. Characteristic length scales arise naturally in experiments displaying localization, but conventional material models are yet size-independent and therefore cannot provide satisfying predictions for simulating strain localization. In addition when aiming at modelling softening mechanisms, numerical simulations using conventional theories display spurious mesh dependency due to the loss of ellipticity of the underlying partial differential equations. As a remedy, regularization methods such as Cosserat, integral and gradient models have been developed extensively in the past few decades also motivated by size effects observed in experiments.

Micromorphic models, which can be seen as relaxed formulations of strain gradient models, have been proved to be able to provide regularization and to predict size effects (Forest, 2009). Recently a reduced micromorphic single crystal plasticity model at finite deformations has been developed (Ling et al., 2018). It involves the gradient of a single cumulated slip variable, making it relatively numerically efficient. We show that this model, depending on the hardening behaviour and along with other variants available in the literature, predicts an increasing and unbounded localization area when simulating slip bands. To address that issue, analytical solutions of this model are derived for a periodic unit-cell in simple shear with a single slip system aligned with the shearing direction. Predictions with linear and non-linear positive and negative strain hardening behaviours as well as perfect plasticity are investigated. Widening of localization slip bands are evidenced in the case of non-linear softening. Therefore an enhanced micromorphic model is proposed which allows to predict bounded localization slip bands width for realistic saturating softening behaviours (Scherer et al., 2018). Analytical solutions are then validated through numerical finite element solutions of the same boundary value problem. The enhanced micromorphic strain gradient crystal plasticity model is finally applied to simulate the behaviour of a periodic porous unit-cell under simple shear which is relevant for nuclear materials application where dislocation glide may form softened bands (or channels) of 10-100 nm width which may localize strain and strongly interact with irradiation induced nanovoids. The effects of void size, void volume fraction, voids periodic lattice, stress triaxiality and slip system orientation with respect to the slip band are investigated.

References

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