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On the application of strain gradient crystal plasticity to study strain localization phenomena in single crystals

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ABSTRACT

Strain localization is an important plastic instability process occurring prior to fracture. It is usually observed in the form of narrow bands of intense plastic shear strain in deformed bodies undergoing severe inhomogeneous deformation. Considering a single crystal with single slip system activated, two types of shear bands, known as slip and kink bands, may occur according to the seminal work of Asaro and Rice [1] based bifurcation analysis.

Conventional crystal plasticity (CCP) theories have widely been applied in the literature to study strain localization within single crystals. Although these theories are able to capture several kinds of localization modes including slip and kink bands, they present mesh-dependence difficulties. In addition, CCP theories identically predict slip and kink bands which appear in this framework as equivalent bifurcation modes. Consequently, CCP theories are not suitable to study localization phenomena in single crystals. These theories include no internal length scale(s) allowing for stabilizing localization which theoretically will occur in a set of zero measure.

A solution to overcome limitations of the aforementioned theories consists in applying nonlocal plasticity approaches. Including internal length scale(s), these approaches provide a natural framework to capture nonlocal effects. One class of nonlocal approaches, which presents auspicious features to capture localization phenomena in single crystals, is the class of strain gradient crystal plasticity (SGCP) theories. This class has been the subject of a large number of recent works mostly focusing on size effects [2, 3]. However, only a few works applying SGCP theories to study localization phenomena can be found in the literature. In almost all existing studies of localization phenomena in single crystals, only higher-order energetic effects have been considered. Higher-order dissipative effects on these phenomena have not yet been explored. Furthermore, there exist no works providing a comprehensive investigation of the abilities of SGCP theories in capturing different kinds of localization modes within single crystals, particularly the competition between slip and kink bands.

The present contribution aims at tackling these tasks. To this end, a finite deformation SGCP model was developed and implemented within Abaqus/Standard using User-Element (UEL) subroutine. This model was applied to simulate a uniaxial tension of a single crystal plate undergoing single slip. The objective of this simulation is to assess the effectiveness of the proposed model in capturing the complex localization behavior with competition between slip and kink bands.

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