A finite strain FE-Implementation of the Fleck-Willis gradient theory: Rate-independent versus visco-plastic formulation

This paper presents a numerical basis for finite strain analysis using the higher order flow theory by Fleck and Willis [2009, A mathematical basis for strain-gradient plasticity theory - part II: tensorial plastic multiplier, J. Mech. Phys. Solids, 57, 1045–1057]. The rate-dependent (visco-plastic) formulation shares similarities with its rate-independent (generalized J2-flow) counterpart, and a combined presentation is laid out. The visco-plastic formulation [2018, A homogenized model for size-effects in porous metals, J. Mech. Phys. Solids, DOI: 10.1016/j.jmps.2018.09.004] is revisited to set the scene for the development of the rate-independent model, but the two formulations differ substantially in the numerical implementation as the rate-independent framework possesses a challenge in determining the yield of individual plastic zones. The framework developed readily accounts for repeated loading/unloading and handles the interaction of multiple plastic zones. The method presented exploits the image analysis techniques that was first combined with the Fleck-Willis theory in Nielsen and Niordson [2014, A numerical basis for strain-gradient plasticity theory: rate-independent and rate-dependent formulations, J. Mech. Phys. Solids 63, 113–127], but extends it to finite strains by adopting an updated Lagrangian framework. Besides somewhat standard extensions to deal with finite deformations, the framework largely resembles that of small strains. In fact, the adopted image analysis can be conducted in the undeformed configuration without any approximations as it relates only to the connectivity of plastic zones on the finite element mesh. The new framework is focused on the deformation and localization in both uniform and notched round bars by formulating the numerical model in an axi-symmetric setup. Comparisons between the visco-plastic and the rate-independent formulations are presented.