Strain localization in thermo-viscoplastic materials

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Abstract

Experimental studies in the literature have often reported formation of strain localization bands, driven by plastic instability, prior to fracture in ductile materials. The onset of localization depends on various factors such as the loading conditions, specimen geometry, strain hardening, strain rate sensitivity and softening due to damage growth and/or adiabatic heating. The critical strain at the onset of localization provides an accurate estimate of the ductility of the material. Analytical models have been developed to predict the critical strain in the quasi-static rate-independent limit (1), under isothermal conditions, using the loss of ellipticity criterion for the equilibrium equations. However, in the rate-dependent case, the equilibrium equations do not lose ellipticity for elastically stiff materials.

Several authors have used a linear perturbation stability analysis to predict the onset of strain localization in rate sensitive materials under dynamic loading conditions. Strain localization occurs when the growth rate of the applied perturbation is large compared to the rate of change of the field quantities. The calculation of the perturbation growth rate is, however, a computationally expensive process and hence not suitable for implementation in finite element codes for fracture simulations. In our work, a close form localization criterion is derived assuming a general form for the plastic potential, that can be specialized to several practical material models. The derived criterion is shown to reproduce several known results from the literature as special cases.

The fracture mechanism in ductile materials involves the nucleation, growth and coalescence of micro-voids. However, localization analyses performed using the widely used Gurson model (2) leads to predictions of unrealistically large failure strains under general loading conditions. This can be attributed to the assumption of dilute porosity in the Gurson model, which ignores the strong interactions between neighboring voids that manifest at finite porosities. Here, a recently developed model of 'inhomogeneous' yielding at the micro-scale of the voids (3), accounting for internal necking and shearing of the inter-void ligaments, is used to perform the strain localization analysis. The predictions of the resulting failure criterion are compared against periodic unit cell model simulations of ductile failure by void growth under proportional loading conditions. The analytical results are found to be in good agreement with the cell model simulations for varying strain rates, strain hardening, strain rate sensitivity and thermal softening exponents. The developed criterion is implemented as a user defined failure criterion in the finite element code, Abaqus. Fracture simulations for notched bars subjected to quasi-static & dynamic loading, ballistic penetration and machining are compared against available experimental data in the literature. References:

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