The effect of microstructural inertia on plastic localization and void growth in porous solids

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Abstract

This paper investigates the impact of microinertia on plastic localization, void growth, and coalescence in ductile porous materials subjected to high strain rates. For that purpose, we have performed finite element calculations on a flat double-notched specimen subjected to dynamic plane strain tension. The simulations employ three distinct approaches to model the mechanical behavior of the porous aggregate: (1) discrete voids within a matrix material governed by von Mises plasticity; (2) homogenized porosity represented using standard quasi-static Gurson-Tvergaard plasticity; and (3) homogenized porosity described with Gurson-Tvergaard plasticity extended by Molinari and Mercier (2001) to account for microinertia effects. The porous microstructures used in the simulations are representative of additive manufactured metals, featuring initial void volume fractions varying between 0.5% and 4%, and pore diameters ranging from 30 μm to 150 μm (Marvi-Mashhadi et al., 2021; Nieto-Fuentes et al., 2023). The applied tensile velocities ranged from 100 m/s to 1000 m/s, producing strain rates between 105 s–1 and 106 s–1, and stress triaxiality values spanning from 4 to 30. The simulations with discrete voids validate the calculations performed using homogenized porosity and microinertia effects, demonstrating that higher strain rates and larger pore sizes lead to slower void growth and a delayed, regularized plastic localization. Conversely, the standard Gurson-Tvergaard model shows notable mesh sensitivity and fails to describe the influence of the loading rate on plastic localization. Ultimately, the comparison between finite element models with discrete voids and those with homogenized porosity illustrates the stabilizing effects of porous microstructure and multiscale inertia on dynamic plastic flow, while also highlighting the strengths of the constitutive model introduced by Molinari and Mercier (2001) for simulating engineering problems involving porous ductile materials subjected to high-velocity impacts.

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