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Incremental variational approaches for micromechanical modeling of effective brittle damage in particulate microstructures

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Extended Abstract

Abstract

This work is devoted to the modelling of the effective behavior of heterogeneous materials containing brittle constituents. The study focuses on a two phases particulate microstructure consisting in spherical (thermo)elastic inclusions dispersed in an elastic-damageable matrix. The local behaviour of the two phases is derived within the framework of generalised standard materials (GSM) for which incremental variational approaches offer a rigorous setting using both energy and dissipation potentials to address the problem of the effective behaviour of the representative volume element by homogenisation. In a previous work, this problem was addressed in two steps (the coupled approach). The damage variable is first determined locally using the variational properties of the incremental potential and leads to a nonlinear formulation with respect to the strain field only. Then a linearisation and minimisation strategy inspired from the FOSO model is adopted in order to obtained the effective behaviour. In the present work, an alternative and more simple linearisation and minimisation approach, initialy proposed by Ben El Barguia (2023), is used (the decoupled approach). It performs simultaneously the minimisation of the linearised incremental potential with respect to both the damage variable and the strain field . The two incremental variational formulations are compared for several representative loading scenarios, including isochoric shear loading and internally driven loading induced by inclusion swelling under various macroscopic boundary conditions. Non-monotonic loading paths, including loading-unloading cycles, are also considered to assess the ability of the models to capture damage irreversibility. For the isochoric shear case, the effective response exhibits linear softening and a fast damage evolution once damage is initiated, validating the computational framework. For the swelling-driven case under zero macroscopic stress, results obtained with the decoupled approach show quasi-identical agreement with those from the coupled formulation previously developed. This strong concordance suggests a possible mathematical equivalence between the two approaches, which constitutes an encouraging result, although formal proof remains to be established. However, despite this consistency, both formulations share a fundamental limitation. When extending the analysis to non-zero hydrostatic macroscopic stress, damage evolution is predicted under both tensile and compressive loading with similar kinetics. This behavior contradicts the physical reality where compression tends to inhibit brittle fracture mechanisms through microcrack closure. This observation reveals an intrinsic limitation of the current constitutive modeling, which does not distinguish between tensile and compressive stress states. Motivated by these findings, the present work constitutes a first step toward the explicit incorporation of tension-compression asymmetry in micromechanical damage models. As an intermediate stage, ongoing research focuses on the determination of effective properties of bimodular elastic materials, whose mechanical parameters depend on the sign of the local volumetric strain. This provides a controlled theoretical and numerical setting to introduce tension-compression asymmetry at the constitutive level, prior to addressing fully brittle damage models.

Keywords:

Micromechanical homogenization Brittle damage modeling Incremental variational approach Tension–compression asymmetry Heterogeneous materials