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Augmented finite element method for progressive damage in complex heterogeneous materials

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ABSTRACT

High-fidelity simulations of damage evolution are approaching realization for a number of material systems, thanks to significant advances in modeling methods and experimental imaging. Nevertheless, significant challenges remain, many of which relate to the difficulty of developing practicable formulations for dealing with materials containing complex material heterogeneity and reinforcement architectures. Heterogeneity poses special problems with the accurate prediction of local stress and strain fields, which can vary strongly with local material features; and with predicting cracks and localized damage bands, which can appear during damage evolution not only on the material boundaries, but also on other surfaces that cannot be specified a priori . In this article, we present a new finite element method named augmented finite element method (A-FEM) that can explicitly account for the arbitrary cracking in either 2D or 3D heterogeneous solids. The A-FEM employs internal nodes to facilitate the subdomain stiffness integration and to describe the strong (or weak) discontinuity across the crack planes (or bonded interface) in a mathematically rigorous way. A local algorithm is used to record the evolving crack front based on local elemental stresses. The crack initiation and propagation is account for by nonlinear cohesive zone models. We shall demonstrate with several classic fracture problems that the numerical performance of our new A-FEM is orders of magnitude more efficient, accurate, and robust when compared with other parallel methods. Finally we shall show that when applied to the complex textile CMCs, the A-FEM can successfully predict the multiple, arbitrary crack development up to final catastrophic failure, and the predicted global stress–strain relations are very consistent with experimental results.