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An integrated approach for statistical microscale homogenization to macroscopic dynamic fracture analysis

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The failure response of brittle materials drastically depends on the variations in fracture strength at the microscale. Non-homogeneous fracture strength fields provide a more realistic prediction of the fracture pattern and failure mechanism. While phenomenological models such as Weibull model capture certain characteristics of brittle fracture, deriving fracture properties from a robust homogenization approach provides a more realistic characterization of material response. Under highly dynamic loadings, the excess energy input to a brittle material is dissipated by forming complex fracture patterns. Fracture patterns not only depend on the material's strength field, but on its elastic properties as the latter can greatly redistribute stress fields even in the absence of any propagating cracks. We investigate the interaction of these two material fields both at the microscale where their field values are characterized and at macroscale where global fracture patterns are predicted under dynamic loading. For the analysis of volume elements at the microscale we use an automated algorithm that turns material microstructure images into finite element meshes. After the elastic and fracture fields are characterized and realized by statistical analyses, we perform dynamic macroscopic fracture analysis using an advanced discontinuous Galerkin method.

In the mesoscale analysis, a 2D finite element mesh is directly generated from the microstructural model using the Conforming to Interface Structured Adaptive Mesh Refinement (CISAMR), which is a non-iterative algorithm that accurately tracks material interfaces and yields high-quality conforming meshes with advanced adaptive operations. The method enables us to perform a highly accurate mesoscale simulation to get more precise homogenized fields for macroscale analyses. The mesoscale analysis is performed on the statistical volume element (SVE). The SVEs provides a higher resolution of the material fields, particularly their spatial variation, than representative volume elements (RVEs). We also analyze the effect of boundary conditions used for the analysis of SVEs in the statistics of homogenized material properties. Finally, the homogenized fields are mapped to macroscale fields as statistical variables through the Karhunen-Loeve (KL) method. The stochastic hyperbolic system of equations is discretized by the asynchronous Spacetime Discontinuous Galerkin (aSDG) method. The aSDG method uses a robust adaptivity strategy in time and space to track fractures and shock waves. We have employed a sophisticated interfacial damage model for fracture kinematics and constitutive laws which accurately models dynamic crack propagation and contact modes.