A multiscale analysis of dynamic fracture propagation in complex materials

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In recent years, the development of increasingly complex materials has accelerated. To obtain a deeper understanding of the behavior of such materials and the underlying processes numerical simulations can be beneficial. One material, that is focus of current research and a promising new option within the construction sector, is fiber-reinforced concrete. In order to enhance the mechanical properties of traditionally used concretes, short fibers are embedded into a fine-grained concrete matrix. This increases its ductility and tensile strength, making it particularly suited for applications where components are potentially exposed to impact loading.

When considering dynamic loads, a detailed understanding of the considered material is particularly important because of the resulting inertia effects and occurring complex wave reflections. Additionally, designed materials with such an elaborate material composition require the incorporation of microscopic effects onto the overall material behavior. Here, microscopically small cracks develop, which propagate and lead to complex fracture networks through coalescence and branching.

In order to simulate all of these processes, a reliable and efficient multiscale framework must be developed, that includes dynamic effects and can handle localization phenomena. This is achieved by using features of the Multiscale Projection Method [1] and the Generalized Finite Element Method with global-local enrichment [2]. The basic idea is to include microscopic aspects into the coarse scale simulation through an additional, more detailed, fine scale analysis within certain areas of interest. This is accomplished by performing a separate simulation, permitting the incorporation of a different, more accurate, material model, or the explicit representation of fibers and micro cracks. Fine and coarse scale are coupled in a concurrent way: first, the displacements obtained from the coarse scale simulation are enforced as boundary conditions for the fine scale problem. Here the phase-field method for fracture is employed, in order to represent the complex fracture behavior of fiber-reinforced concrete. The displacement field obtained from this simulation is then used to construct a numerical enrichment, that reproduces the displacement jump across cracks on the coarse scale. Moreover, the material degradation resulting from the phase-field formulation on the fine scale is projected back to the coarse scale, in order to account for the loss of stiffness within damaged material.

Since incorporating dynamic effects and fracture into multiscale simulations can be problematic due to spurious wave reflections at domain boundaries and crack surfaces, simplified 1D investigations are conducted. From these studies, conclusions can be drawn on possible modifications of the method, such as an improved enrichment strategy, so that even complex 3D problems with advanced materials, like fiber-reinforced concrete, can be modeled.

With the help of this multiscale method, the simulation of dynamic fracture propagation in complex materials is possible. The influence of underlying micro structural effects is included within restricted areas, while the overall structural analysis is kept simple and efficient.

References

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