Investigating Brittle Fracture with an Adaptive Phase-Field Model using the Scaled Boundary Finite Element Method in Three Dimensions

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The phase-field method (PFM) has been successfully applied to simulate damage mechanisms in a wide range of materials including ceramics, metals, and polymers. It has also been used to study various types of loading such as tension, compression, and shear. The PFM has proven to be a powerful tool for understanding and predicting the behavior of crack propagation in materials. This method represents the crack by regularizing its surface over a small width, referred to as the length scale. To simulate the steep variation of the phase-field, a very fine mesh is needed in the damaged area, which leads to high computational costs, particularly if a uniform mesh is used [1]. However, the use of adaptive mesh refinement techniques can help to reduce the computational cost and increase the accuracy of the simulations.

In this research, we develop an adaptive phase-field simulation of fracture in 3D by utilizing an automatically generated octree mesh, analyzed through the scaled boundary finite element method (SBFEM). The simulations rely on 3D digital images as inputs. The mesh is automatically generated from these digital images, where the size ratio between two adjacent hexahedrons is limited to 2:1. This mesh configuration ensures a limited number of unique elements according to the position of the hanging nodes and thus contributes to reducing the computational effort and resources.

The analysis of the automatically generated octree mesh is performed using the scaled boundary finite element method (SBFEM). This semi-analytical method simplifies the analysis of polyhedral elements. Here, only the discretization of the faces of the domain is required [2]. Adaptive mesh refinement is achieved using an error indicator based on the SBFEM solution. This allows for a more efficient use of computational resources by only refining the mesh in areas where it is necessary. The staggered solution scheme outlined by Miehe et al. [2] is used to solve the system of coupled nonlinear differential equations for the phase-field variable and the displacement. The hybrid phase-field method is adopted, assuming that the phase-field evolution is driven only by the elastic tensile energy, resulting in linear differential equations for the displacements [3]. To evaluate the performance of the proposed method, several 3D benchmark examples are presented. These examples demonstrate the accuracy and efficiency of the proposed method and its ability to handle various types of fracture problems.

References

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