Hessisches Kompetenzzentrum
für Hochleistungsrechnen

Computational Continuum Mechanics (CCM)



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Clusters
Lichtenberg Cluster Darmstadt

Additional Software
FEniCs

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Introduction

Fracture is an everyday phenomena which describes the partial or full separation of a body. Fracture is driven by micromechanical processes but our interest is the macroscopic scale, therefore the concept of continuum mechanics is used to describe the overall material behavior. The beginning of fracture mechanics goes back to theoretical work done by A.A. Griffith in the early 1920s where he studied stress and failure in brittle materials due to crack propagation. In the 1940s his work was taken up by G.R. Irwin and extended to ductile materials. Furthermore Irwin found out that the loading of cracks can be divided into three different modes where the first mode describes a tensile load applied perpendicular to the crack plane. The second mode describes a shear loading parallel to the crack plane and the third mode is an out of plane shear loading. However it is not only important to investigate different loading types but also the forming and propagation of cracks in different materials. The evolution of cracks in glacier ice is an interesting research field since ice is a viscoelastic material with a short term elastic behavior and a long term viscous behavior. The break off of ice bergs from ice shelves and tidewater glaciers, so-called calving, is one of the main mass loss mechanism however this process is poorly understood. Therefore physical based models of fracturing and the simulation of cracks are needed to get a better insight in this process.

Methods

To model the onset and evolution of cracks the phase field method has become established in computational mechanics

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over the last years. In this method a continuous scalar field *s(x, t)* is introduced, approximating the crack. A value of $s = 1$ in the phase field parameter represents the fully intact material and $s=0$ indicates the broken material. As the phase field is continuous the sharp discontinuity of a crack is smeared out over a small length scale. The method has a lot of advantages as it does not require remeshing and can simulate complex crack phenomena like crack initiation or crack branching. We implemented the phase field method for fracture in the finite element framework FEniCs and studied the different loading modes. Since the evolution of the crack path requires high computational resources wherefore the code was parallelized. For the fracture in glacier ice we implemented the phase field method for viscoelastic materials and set up a geometry mimicking a typical situation at calving fronts of floating ice masses in Greenland and Antarctica. There fractures occur in the vicinity of locally grounded locations, called pinning points.

Results

The results of the crack path in the tensile and shear loading scenarios are coherent and in accordance with theoretical work. The stress intensity factors which are used to predict the stress state at the crack tip are in good agreement with the theory. Within a benchmark test the influence of the mesh resolution and length scale was investigated. In this project a phase field for fracture in viscoelastic materials was developed and used to simulate cracks in glacier ice. The simulated cracks arise at pinning points and start growing perpendicular to the ice flow direction into the ice mass. This evolution of the crack paths are in good agreement with typical crack patterns that occur in Greenland and Antarctic ice masses and have been observed by satellite imagery.

Discussion

The results of the different loading cases helped on understanding the phase field method for fracture and the validation of this method. The benchmark test for mode I, the opening mode and mode II, the case of shear loading, verified our implementation and agree with analytical solutions. The work on cracks in ice has shown that the phase field approach is a promising approach to a physical based model. So far, only small strain theory was used throughout the simulations. To simulate the crack evolution over a longer time scale this is no longer possible due to large displacements. Therefore we want to incorporate the finite strain theory, which involves an adjustment of the phase field method in the future. Furthermore it would be interesting to investigate other scenarios than pinning points where cracks occur in glacier ice.

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Publications

Sondershaus, R.; Müller, R.: "Phase field model for simulating fracture of ice", ECCOMAS Congress 2022 - 8th European Congress on Computational Methods in Applied Sciences and Engineering, 2022

Sondershaus, R.; Müller, R.: "Fracture simulations of ice with the phase field method", CMM-SolMech 2022, 24th International Conference on Computer Methods in Mechanics (CMM) and 42nd Solid Mechanics Conference (SolMech), 2022

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