An enriched phase-field approach for the efficient simulation of fracture processes in 2D

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During the last decade, the phase-field method for fracture has become one of the most popular approaches for the simulation of cracks and their propagation. The main advantages of the phase-field method are its easy implementation and its capability to automatically detect when, in what direction and how far a crack propagates without the necessity for additional criteria. Even crack branching and crack coalescence are captured automatically. The phase-field method has been applied to brittle and ductile fracture and to quasi-static and dynamic crack propagation. Inherent to the phase-field theory of fracture is a small length scale parameter which is responsible for the width of the smeared crack reflected by the phase-field. In the classical phase-field method, the element size needs to be significantly smaller than that length scale parameter leading to very large meshes even for 2D problems. In addition to that, even for linear elastic fracture mechanics problems, a phase-field formulation leads to a highly nonlinear finite element problem. The combination of very fine meshes and high nonlinearity leads to an enormous computational effort which is the biggest disadvantage of the phase-field method.

In contrast to the phase-field method, the extended finite element method (XFEM) or the generalised finite element method (GFEM) are able to capture the discontinuity of the displacement field due to a present crack within an element very accurately by means of properly defined enrichment functions. These enrichment functions require a geometric description of the crack position e.g. by means of an additional explicitly given mesh for the crack surface or by means of level sets. For the XFEM/GFEM it is also necessary to evaluate additional criteria for crack propagation simulations. The biggest advantage of the XFEM/GFEM is its rather low computational effort even for 3D simulations and the mesh independence of the sharp crack geometry. However, due to the necessity for an additinal geometric representation of the crack and the dependence of the enrichment functions on the crack geometry, the simulation of e.g. crack coalescence or crack branching in 3D is rather difficult.

In the present approach we combine the advantages of the phase-field method with the advantages of the XFEM/GFEM. The extended phase-field method (XPFM) [1] is based on a classical phase-field approach for which a locally transformed ansatz is chosen for the phase-field and an enriched ansatz similar to the XFEM/GFEM is chosen for the displacement field. The enrichment function for the displacement field is based on the phase-field. As a consequence, an additional geometric representation of the crack is not necessary to evaluate the enrichment function. The transformed phase-field ansatz in addition to the enriched displacement field ansatz allow for significantly coarser meshes compared to the classical phase-field method as well as displacement discontinuities within elements similar to the XFEM/GFEM. Various examples in 2D compare the performance and accuracy of the XPFM approach with the classical phase-field method.

References

[1] S. Loehnert, C. Krüger, V. Klempt, L. Munk, An enriched phase-field method for the efficient simulation of fracture processes, Computational Mechanics, accepted (2023).