An eXtended Phase-Field Method (XPFM) for the Simulation of Fatigue Fracture Processes

C. Krüger[1]*, V. Klempt[1], S. Loehnert[1]

[1] Institute of Mechanics and Shell Structures, Faculty of Civil Engineering, Technische Universität Dresden, August-Bebel-Straße 30, 01219 Dresden, Germany, christian.krueger@tu-dresden.de

Most engineering structures undergo changing cyclic loads which can lead to fatigue fracture and failure. Nowadays, numerical methods can help to facilitate an estimation of the life span of these structures. Among others, the eXtended Finite Element Method (XFEM) [1] and the Phase-Field Method (PFM) [2] are methods which can deal with crack propagation processes. During the last decade, the PFM gained increasing popularity because crack phenomena like crack initiation, propagation, branching and merging can be handled without the need for further criteria like within the XFEM. The effort of implementation is also lower compared to the XFEM, but the computational costs are quite high since a rather fine finite element discretisation around the crack is necessary in order to achieve an acceptable low error. Nevertheless, a mesh-independent crack representation is, contrary to the XFEM, not possible. Without loss of accuracy much coarser meshes can be applied in the XFEM compared to the PFM.

Recently LOEHNERT ET AL. [3] proposed the eXtended Phase-Field Method (XPFM). This method combines benefits of both, the XFEM and the PFM. A transformed ansatz for the phase-field is introduced, based on the exponential solution of the one-dimensional phase-field problem in [2]. Furthermore, an enriched displacement field ansatz, where the enrichment functions are coupled to the transformed phase-field degrees of freedoms, is added. Herby it is possible to retain the crack initiation and propagation characteristics of the underlying phase-field approach on much coarser meshes independent on the orientation of the finite elements. Thus, the number of degrees of freedom can be reduced significantly in contrast to the original phase-field approach.

A phase-field model for fatigue fracture processes has been presented by CARRARA ET AL. [4]. There, a history-depended degradation of the fracture toughness is proposed. The model is able to reproduce fatigue phenomena like WÖHLER curves or the PARIS law. In this contribution, this fatigue approach is coupled with the developed XPFM for the two-dimensional case. It is shown, that the features of the phase-field fatigue model can be reproduced despite the reduced numerical effort of the XPFM on coarser meshes.

Due to the non-linear transformed phase-field ansatz and the non-polynomial enrichment functions, a sufficiently accurate integration method is required apart from standard GAUSS-integration. Beyond, an adequate convergence criterion for the nested staggered and enrichment update solution process is discussed. Several numerical examples are shown to demonstrate the coupled extended phase-field fatigue method.

References

[1] T. Belytschko, T. Black, Elastic crack growth in finite elements with minimal remeshing, Int J Numer Methods Eng 45(5) (1999) 601–620.

[2] C. Miehe, F. Welschinger, M. Hofacker, Thermodynamically Consistent Phase-Field Models of Fracture: Variational Principles and Multi-Field FE Implementations, Int J Numer Methods Eng 83(10) (2010) 1273–1311.

[3] S. Loehnert, C. Krüger, V. Klempt, L. Munk, An enriched phase-field method for the efficient simulation of fracture processes, Comput Mech *submitted* (2023).

[4] P. Carrara, M. Ambati, R. Alessi, L. De Lorenzis, A Novel Framework to Model the Fatigue Behavior of Brittle Materials Based on a Variational Phase-Field Approach, Comput Methods Appl Mech Eng 361 (2017) 112731.