A locally adaptive phase-field model that tracks sharp cracks

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Various adaptive phase-field models of fracture have been proposed recently [1]. Our adaptive refinement strategy [2] is based on considering only two types of elements in a fixed background mesh: h-refined elements along cracks, where a higher spatial resolution is needed, and standard elements in the rest of the domain. The strategy is specifically designed to avoid remeshing, transition elements or the handling of hanging nodes. Continuity of the displacement and damage fields in the non-conformal interface between adjacent elements of different type is imposed in weak form by means of Nitsche's method. This weak imposition of continuity leads to a very local refinement in a simple way: no tuning of Nitsche's parameter is required. The robustness of the approach is illustrated by several examples, including branching and merging of multiple cracks in 2D, and twisting cracks in 3D.

This adaptive phase-field approach is the starting point for a continuous-discontinuous model of fracture [3]. The phase-field equations are solved only in small subdomains around crack tips to determine propagation. With computational cost in mind, an XFEM discretization is used behind the tips to represent sharp cracks; this enables derefinement of the refined elements. Crack-tip subdomains move as cracks propagate in a fully automatic process. The continuity of the displacement field in the interface between the phase-field refined subdomains and the XFEM region is again imposed in weak form via Nitsche's method. In this continuous-discontinuous approach, the phase-field model plays the role of a crack tracking citerion that handles in a natural manner crack branching and merging. This versatility contrasts with the limitations of classical criteria in linear elastic fracture mechanics to determine crack direction (e.g. maximal tensile stress criterion, stress intensity factor criterion).

The combined phase-field/XFEM approach [3] is tested with the same set of examples as the plain phase-field approach [2]. A very good agreement is obtained in terms of force-displacement response and crack path, with a signicant decrease in the computational cost: whereas the number of degrees-of-freedom in the phase-field approach increases as the cracks propagate and more elements are refined, it stays essentially constant in the combined approach, because refined elements are only needed in the crack-tip subdomains.

References

[1] M. Rohracker, P. Kumar, J. Mergheim, A comparative assessment of different adaptive spatial refinement strategies in phase-field fracture models for brittle fracture, Forces in Mechanics, 10, 100157, 2023.

[2] A. Muixí, S. Fernández-Méndez, A. Rodríguez-Ferran, Adaptive refinement for phase-field models of brittle fracture based on Nitche's method, Comput Mech, 66, 69–85, 2020.

[3] A. Muixí, O. Marco, A. Rodríguez-Ferran, S. Fernández-Méndez, A combined XFEM phase-field computational model for crack growth without remeshing, Comput Mech, 67, 231–249, 2021.