Phase-field modeling of fracture in brittle materials with anisotropic fracture energy

Sindhu Nagaraja[†], **Marreddy Ambati**[†] **and Laura De Lorenzis**[†]

[†] Institute of Applied Mechanics, TU Braunschweig, Pockelstraße 3, 38106 Braunschweig, Germany.
e-mail:{s.nagaraja, m.ambati, l.delorenzis}@tu-braunschweig.de
Web page: https://www.tu-braunschweig.de/iam

ABSTRACT

Materials involved in several practical applications for e.g. arterial tissue, silicon in photovoltaics, extruded polymers, composites, laminates are seldom isotropic as a consequence of their inherent microstructure or due to the undergone fabrication process. This class of materials exhibits anisotropy in the fracture properties in addition to elastic anisotropy. In these materials, the fracture toughness G_c is no longer a constant but is direction dependent, $G_c(\boldsymbol{n})$ ($\boldsymbol{n}$ is the normal to the crack surface) in 3D or simply $G_c(\theta)$ in 2D. Depending on the convexity of the polar plot $G_c(\theta)$, they can be classified into weakly (if convex) and strongly (if non-convex) anisotropic materials.

In the well established phase-field modeling of fracture framework a discrete crack is approximated by the steep local variation of a continuous scalar field called the phase-field d varying between 0 at intact material points and 1 in a fully damaged region, along with an associated length-scale. Evolution of the phase-field variable based on the minimization of the phase-field regularized total energy functional governs the fracture process in an isotropic material. The non-local nature of this framework provides a readily extendable platform to model anisotropic fracture energies.

Extension of such a model to account for anisotropic fracture energies has attracted considerable research recently. To model anisotropic materials exhibiting weak anisotropy, a class of models incorporating a second order structural tensor resulting in an orientation dependent length-scale with which a convex orientation dependent fracture energy $G_c(\theta)$ is achieved has been discussed in e.g. [1]. However, for strongly anisotropic materials, the Griffith's energy functional itself becomes ill-posed due to the non-convexity induced by the fracture toughness [2]. This ill-posedness is removed in the phase-field approach by including higher gradients of the phase-field that are related to the curvature energy. Associated to this is also a fourth order structural tensor carrying the anisotropy details of the underlying material.

The research presented in this work focuses on understanding the significance and influence of the individual terms and the anisotropy inducing ingredients that occur in the phase-field framework. Simple numerical experiments unveiling the attributes of the discussed phase-field fracture method are studied within a finite element and isogeometric analysis based computational environment. Numerical examples also demonstrate the capabilities of the method in modeling the key features associated with fracture in anisotropic media.

REFERENCES

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