Crack kinking in a variational phase-field model of brittle fracture with strongly anisotropic surface energy

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ABSTRACT

In strongly anisotropic materials the orientation-dependent fracture surface energy is a non-convex function of the crack angle. In this context, the classical Griffith model becomes ill-posed and requires a regularization. We revisit the crack kinking problem in materials with strongly anisotropic surface energies by using a variational phase-field model. The model includes in the energy functional a quadratic term on the second gradient of the phase-field. This term has a regularizing effect, energetically penalizing the crack curvature. We provide analytical formulas for the dependence of the surface energy on the crack direction and develop an open-source finite-element solver for the higher-order phase-field problem. Quantitative numerical experiments for the crack kinking problem show that the crack kinking directions observed in our phase-field simulations are in close agreement with the generalized maximum energy release rate criterion. Finally, we revisit a thermal quenching experiment in the case of slabs with strongly anisotropic surface energies. We show that the anisotropy can strongly affect the observed crack patterns, either by stabilizing straight cracks or by inducing zig-zag crack patterns. In the case of zig-zag cracks, we observe that crack kinking is always associated with an unstable propagation of a finite length add-crack in a single time-step.

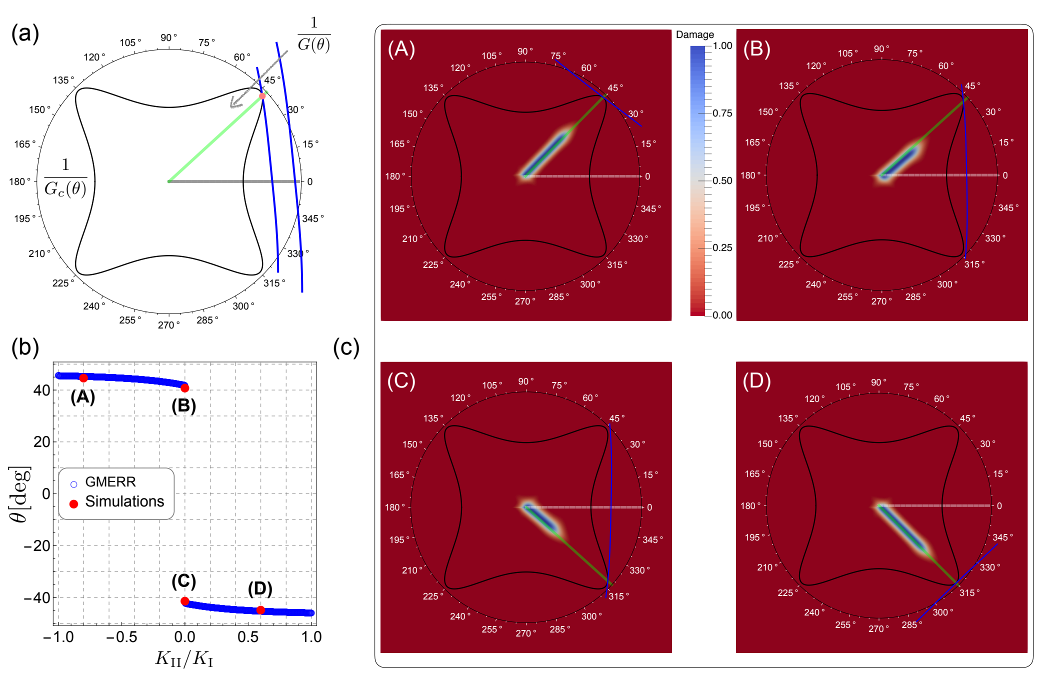

Figure 1: Kinking angle as a function of the mode-mixity factor $K_{\mathrm{II}}/K_{\mathrm{I}}$ for the strongly anisotropy surface energy $G_c(\theta) = \sqrt[4]{1.0 + 0.8\cos 4\theta}$. (a) Graphical solution of the Generalized Energy Release Rate criterion; (b) Crack kinking angles as a function of the mode-mixity factor; (c) Snapshots of the damage field α immediately after the kinking for $K_{\mathrm{II}}/K_{\mathrm{I}} = \{-0.8, -0.01, 0.01, 0.6\}$ (from A to D), superposed with the corresponding graphical solutions of the GMERR criterion.