On the Use of Discontinuous Damage Models for Mixed-Mode Fracture

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The onset of micro-cracking in quasi-brittle materials commonly occurs perpendicularly to the maximum principal stress direction. Nevertheless, crack evolution may not necessarily occur in mode-I, due to e.g. aggregate interlocking, which develops between crack faces of the discontinuity. Consequently, the ability to simulate mixed-mode fracture in these materials is of utmost importance.

In the present work innovative damage-based material models for strong discontinuities in quasi-brittle materials are introduced. In the proposed models all failure modes are considered, namely mode-I fracture, pure mode-II fracture, mixed-mode fracture and also mode-II under compressive tractions.

The introduced material models are developed in a strong discontinuity framework, such as the discrete interface approach, the embedded strong discontinuity approach [1] and XFEM. In order to overcome the common and recurrent convergence problems associated with the iterative numerical schemes, when dealing with the softening behavior of quasi-brittle materials, the proposed models can make use of a non-iterative numerical scheme, first introduced by Graça-e-Costa et al. in [2], which was partially inspired by the sequentially linear approach by Rots et al, [3]. The use of these non-iterative schemes is made possible with the definition of both total and incremental approaches within the proposed material models.

The first material model makes use of kinematic internal variables and is presented both in: i) an isotropic setting, being a generalization of the mixed-mode model presented by Alfaiate et al. in [4], and in ii) a non-isotropic setting, in which crack closure under compressive stresses can be properly taken into account. In the second material model, the definition of a limit surface in the traction space is required, based on which the damage evolution law is defined. This model is also presented in an isotropic and non-isotropic variant, in which, in the latter case, different evolution rates are adopted in mode-I fracture and mode-II fracture.

It is worth noting that the proposed models may also capture a characteristic feature of quasi-brittle materials, namely the dilatancy effect. In order to assess and validate the results of the proposed models, several relevant numerical examples were studied.

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