Crack propagation in quasi-brittle materials using a FEM-VEM tracking algorithm

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Quasi-brittle materials mainly fail when, in the presence of specific stress scenarios, strains localize in narrow bands. Most of the computational strategies are developed in the framework of the finite element method (FEM) and can be divided into discrete crack models or smeared crack models. Discrete crack models introduce a strong or weak discontinuity along the inter-element boundaries or inside the element (intra-element discontinuity).

This work is inspired by the Augmented-FEM strategy [1]. A-FEM is a discrete crack model consisting in dividing the cracked element in two standard finite elements and a nonlinear interface where discontinuities localize. The additional degrees of freedom introduced to decompose the element are condensed at the equilibrium level, therefore are not present at the global level. An advancement of A-FEM was proposed in [2] and consisted in the use of a zero-thickness interphase model (IPH) [3] in place of the interface (ZTI), adding internal stresses and strains to the contact ones. Unlike ZTI models, IPH does not require a specific traction-displacement jump constitutive law and the constitutive laws adopted for IPH can correspond to those of bulk material, thus reducing the number of constitutive parameters.

Confirming advancements in [2], the innovative point of the present work resides in the description of the two sub-elements through the virtual element method (VEM) instead of FEM.

The VEM [4]-[5] is more flexible than standard FEM, since the element can be a polygon characterized by any number of edges, without constraints, with the ability to accurately deal with complex geometries, no need of a parent element, easy polynomial degree elevation, very good performances for distorted meshes.

The proposed crack tracking procedure starts with a discretization of the domain using standard finite elements. Known localization criteria and the spectral analysis of the fracture tensor built at the element level identify those elements crossed by a crack and crack orientation. Localized elements are then grouped into substructures, namely portions of the structure characterized by unique continuous cracks. Cracks are made continuous on the basis of simple heuristic criteria. Substructures are composed of virtual elements and IPHs representing discontinuities. At the global level, equilibrium is iteratively achieved by taking into account internal forces from substructures. These are solved in a VEM framework by imposing, as essential boundary conditions, displacements at nodes shared with the rest of the structure. Because the original element could be divided into very distorted sub-elements or non-standard elements, the VEM is more performant than the FEM. The main features of the adopted strategy are illustrated through benchmark examples.

References

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