Virtual element method for mixed-mode cohesive fracture simulations

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The Virtual Element Method (VEM) has attracted a lot of interest from the scientific community and numerous results have been achieved in different research fields, comprising linear elasticity problems, inelastic problems, fluid-flow problems and contact problems [1]. In particular, VEMs can be conveniently applied within the context of computational fracture mechanics.

In this field, the numerical approaches proposed in literature are mainly based on the finite element method (FEM) or on modified forms of this latter such as the extended FEM and the augmented FEM.

The VEM formulation is characterized by the possibility to define polygonal meshes with elements characterized by any number of edges and by the flexibility in mesh generation that allow to introduce a crack just redefining the element in two different elements joined by a crack modelled with an interface element. The features of the VEM appear particularly suitable for the development of a procedure able to follow the crack propagation in a solid, requiring a minimal remeshing [2].

The present work proposes an algorithm of nucleation and growth for fracture evolution in 2D cohesive media. The procedure is based on virtual element method specifically referred to a 4-side 12-node virtual element with piece-wise linear approximation of the displacement field on the edges. The large number of nodes and, consequently of degrees of freedom, is exploited to enrich the strain field evaluation. It is derived by means of the minimization of the complementary energy within the single element. This procedure allows to avoid the stabilization of the element stiffness matrix.

The fracture is introduced in the solid domain by splitting the virtual element, called parent element, into two slave elements, joined by a cohesive interface. The presence of the two nodes inside any edge of the parent element has been proposed for avoiding the generation of new nodes during the crack evolution. The obtained slave elements are characterized by a different number of nodes depending whether the straight crack within the parent element crosses two opposite or adjacent sides. At the interface, a cohesive law governed by a damage variable in mode I, in mode II and in mixed mode, and that takes into account for the unilateral effect due to the reclosure of the crack in compression, is adopted [3].

Moreover, the fracture direction is defined as the orthogonal to the maximum tensile principal nonlocal stress evaluated around the crack tip for the fracture growth, and in the element center for the nucleation. The maximum tensile principal nonlocal stress is computed averaging on the mesh, by means of a weight function, the stress field evaluated via complementary energy within each element.

Numerical simulations of experimental tests are developed in order to assess the ability of the proposed procedure to satisfactorily reproduce the crack nucleation and growth. The simplicity of the procedure with respect to other more complicated approaches is remarked highlighting the reduced computational effort and storage memory required.

References

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