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Eigenerosion: extension and applications to heterogeneous media

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In 1921, Griffith introduced the concept of energy release rate in brittle fracture: below a certain amount of energy, no crack extension can occur. A variational formulation of this idea has been proposed by Francfort and Marigo [1] in the late 90’s whose a regularization (1) has been recently developed by Schmidt et al. [4].

\[ F_\epsilon(u, \varepsilon^*, t) = \int_{\Omega} W(\varepsilon(u) - \varepsilon^*) \, dV - \int_{\Gamma_f} \mathbf{T} \cdot u \, ds + G_c \frac{|C_\epsilon|}{2\epsilon} \]

where \( T \) is the applied traction on the part \( \Gamma_f \) of the boundary of the domain \( \Omega \), \( W \) is the elastic strain energy density of the body, \( \varepsilon(u) \) is the strain operator of linear elasticity, \( \varepsilon^* \) is an eigendeformation field [2], \( G_c \) is the critical energy-release rate and \( \epsilon \) is a small length which defines \( C_\epsilon \) an \( \epsilon \)-neighbourhood to the crack, \(|D|\) is the measure of any domain \( D \). When \( \epsilon \) tends to zero the standard Griffith’s theory is recover.

The minimization of the functional (1) within the finite element framework was firstly realized by Pandolfi and Ortiz [3] in the context of homogeneous elastic media. These authors proposed to model the crack propagation associated to the eigenerosion using a 'killing element' method (deletion of elements verifying the crack propagation criterion). Two physical quantities are involved in this process.

- A variation of energy.

\[ -\Delta E_K = \frac{1}{2} u^T \Delta S_K u + \frac{1}{2} u^T S_K^{-1} \Delta S_K u \]
where $\Delta S_K$ is the stiffness matrix of the $K$-th element, $S$ is the stiffness matrix of the meshed body where the element $K$ is removed and $u$ the displacement field before the erosion or equivalently before the assumed crack propagation. For sake of simplicity, [3] have taken into account only the element contribution in the equation (2).

- A crack length increment. For a crack occupying a domain $C$, the size of its extension is evaluated by a neighbourhood process [3]:

$$\delta A(K) = \frac{|(C \cup K)_c \setminus C_e|}{2\epsilon},$$

(3)

where $(C \cup K)_c$ is the current neighbourhood of the crack, $C_e$ is the previous configuration of the crack-neighbourhood and $K$ is the current killed element. When $\epsilon$ tends to 0, $\delta A(K)$ approaches the physical increment of the crack.

In the present work, 1/ we investigate a criterion with a both local-global energy, 2/ we propose an extension of the eigenerosion method to fracture dynamics, 3/ we point out and clarify some technical problems related to the crack length increment (new crack-neighbourhood process, crack-boundary interactions, crack-crack interactions) and 4/ we extend the eigenerosion method to heterogeneous media. Each development is validated on benchmark.

The extension to heterogeneous media is based on a local predictor-corrector method. The prediction phase consists in determining the elements that are candidates to the erosion process, i.e. that maximize the ratio $-\Delta E_K/[\delta A(K) G_c(K)]$ over the structure, where $G_c(K)$ denotes the critical energy release rate of the $K$-th element depending on the underlying phase. This extension to heterogeneous media is applied to an engineering problem: the study of the crack tortuosity in concrete media. The effect of two distinct parameters is studied: the aggregates volume fraction and the size polydispersity of the aggregates.

Moreover, the extension of the method to the 3D case is actually studied.

References


