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# ANALYTICAL DEVELOPMENT AND NUMERICAL SIMULATION OF COHESIVE CRACK INITIATION AND PROPAGATION COUPLED WITH PLASTICITY

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Griffith's theory of fracture [1] based on the concept of critical energy release rate $G_c$ remains the most used in fracture mechanics thanks to its simplicity in terms of material behavior. However, this theory contains many major drawbacks. On the one hand, it is in general impossible to initiate crack from a sound body because of the stress singularity at the crack tip. On the other hand, the crack propagation with the presence of the plasticity in the sound part of the body is not extensively investigated. Dugdale [2] and Barenblatt [3] introduced new formula of crack surface energy that is a continuous, monotonically increasing and concave function in term of displacement jump to extend the drawbacks of Griffith's theory. According the authors, a cohesive zone locates between the cracked part and the sound part of the body where the crack lips are subjected by cohesive force. Besides, it should be noted that the energy dissipation by plasticity plays an important role in the fracture mechanism of ductile materials. By using the Barenblatt-type surface energy and elasto-plastic bulk energy, the local minimization of total energy in term of state variables (displacement filed $\mathbf{u}$, plastic strain $\boldsymbol{\varepsilon}_p$, accumulated plastic strain $p$) [4] provides an appropriate way to study the criterion of crack initiation and the stability of crack propagation. The first and second local stability conditions of the total energy are investigated.

In this paper, we are interested in analytical development and numerical simulation of crack initiation and propagation in ductile fracture mechanics. In the first part of the paper, the analytical one-dimensional and three-dimensional modeling of crack initiation and propagation for ductile materials are developed by using the cohesive zone model. A characteristic length of material is introduced in one-dimensional problem. The crack initiation criterion in a three-dimensional body is described as an intrinsic cohesive curve in

stress plane $(\sigma_{nn}, \sigma_{nt})$. This result explains adequately the dependence of critical principal stresses on the stress triaxiality proposed in the microstructural fracture model of Gurson-Tveergard-Needleman [5]. Moreover, the crack initiation criterion independent from the actual stress field is very practical in numerical application of fracture mechanics.

The second part of the paper focuses on the numerical implementation of the analytical results in finite element software *Code_Aster* developed by EDF R&D since 1989. The mixed interface finite element [6] is employed for the numerical investigation of cohesive crack. The localization of crack initiation and the direction of crack path are characterized by using the intrinsic cohesive curve of material. The numerical simulation agrees well with these position of crack initiation obtained in experimental tests conducted on axisymmetrical specimens. These results would provide *Code_Aster* the possibility of studying the crack evolution without pre-defined crack path.

In the future work, the stability of the analytical three-dimensional solution will be studied. The Barenblatt-type surface energy that depends on the plastic strain will be implemented in the analytical modeling. The crack propagation after crack initiation is investigated numerically in *Code_Aster* by using the mixed interface finite element and the elasto-plastic behavior of material.

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