Thermomechanical Fracture Dynamics in Heterogeneous Media using Cohesive Zone Models. Application to Ageing of Concrete.

†L. Bichet[1,3], F. Dubois[1,3], Y. Monerie[1,3] and F. Perales[2,3]

[1]Laboratoire de Mécanique et Génie Civil (LMGC), Université de Montpellier, CNRS, Montpellier, France
[2]Institut de Radioprotection et de Sûreté Nucléaire, CE Cadarache Bât. 702, BP3-13115 Saint-Paul-lez-Durance, France
[3]Laboratoire de Micromécanique et Intégrité des Structures, Université de Montpellier, CNRS, IRSN, France

†Corresponding and presenting author: lionel.bichet@umontpellier.fr

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During their life in a nuclear power plant, the operative equipments may be exposed to cyclic or transient thermomechanical loads. This paper investigates from a numerical point of view the fracture dynamics under those conditions in an ageing cement based material.

The numerical approach rests on the Non Smooth Fracture Dynamic (NSFD) method [1] for the mechanical effects and consists in: 1/ a cohesive-volumetric multibody (finite element and/or rigid) approach 2/ complex surface interaction laws embedded between two bodies (mesh-mesh, mesh-rigid, rigid-rigid) 3/ the Non Smooth Contact Dynamics solver [2]. The thermal effects are taken into account through a sequential mechanical-thermal coupling.

The surface damage parameter β ($\beta = 1$ represents sound cohesive zone, $\beta = 0$ a completely broken interface) is enriched by a discontinuous thermal field. A cohesive flux $\boldsymbol{\phi_{CZM}}$ is introduced between each body (heat equation) with a dependence on the damage parameter β. The flux through the cohesive zone is written as [3]:

$$\boldsymbol{\phi_{CZM}} = \lambda_{CZM} \nabla T_{CZM} \text{ with } \lambda_{CZM} = \beta \lambda_\beta + (1-\beta)\,\lambda_{(1-\beta)},\ \beta \in [1,0]$$

where λ_{CZM} is the overall conductivity of the thermal cohesive zone model, λ_β the conductivity of the undamaged part and $\lambda_{(1-\beta)}$ the conductivity through the damaged part (depending on the fluid penetrating into the crack). The authors propose to solve the system according to the value of β: while $\beta = 1$, the nodes of the exploded mesh are merged then the expression of $\boldsymbol{\phi_{CZM}}$ is used. With this strategy, the thermal crack closure contact is also taking into account.

A wide panel of chemical reactions is the source of the ageing behaviour of a cement based material. As an example, the alkali-silica reaction [4] is caused by late formation of ettringite. An expansive gel around the aggregate appears and leads to the initiation and the propagation of microcracks at the interface between the matrix and the aggregate. These microcracks are here represented by cohesive zone model initially partially broken between the aggregate and the matrix. A thermomechanical analysis is proposed on Figure 1. A temperature is imposed ($T_{imp} = 150\,^\circ C$) on the right side of a square plate containing a circular inclusion. The plate is initially at $T_{ini} = 0\,^\circ C$ and the inclusion has a dilatation coefficient larger than the one of the matrix. Depending on the location of an initial microcrack, various crack path are observed. When the microcrack is located in front of the inclusion with respect to the thermal front (left on Figure 1), the arriving dilatational front induces a propagation of the crack through the entire cell. Since the proposed model predicts a drastic decrease of the conductivity when the crack evolves, this situation leads to a kind of thermal barrier and the back of the cell remains cold. When the microcrack is located behind the inclusion (middle), the thermal front can propagate into the inclusion and the dilatation of this inclusion induces a shear stress at the microcrack tip: again, a propagation of the crack through the entire cell is observed and the back of the cell remains cold. For the intermediate situation (right), the crack propagation is less symmetric and a diffusion of the temperature in the still sound part is observed. The temperature of the back of the cell increases.

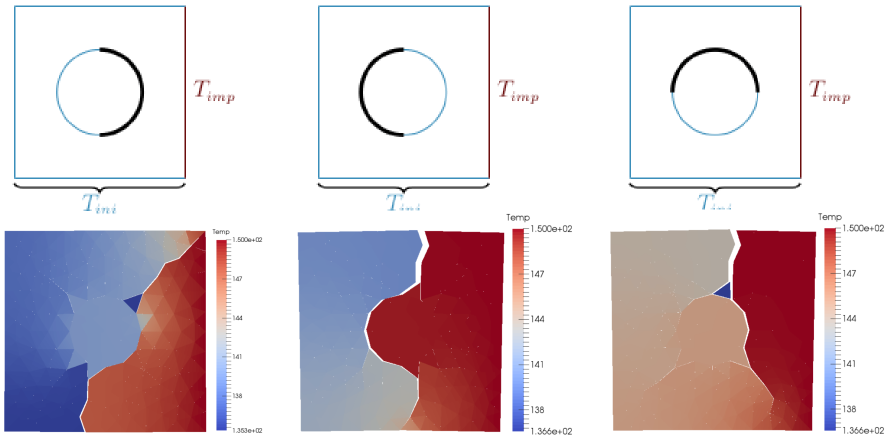

Figure 1: Thermo-mechanical analysis of a predegraded matrix-inclusion cell. Thermal field an crack path.

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