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# Advanced modelling with the X-FEM of dynamic crack propagation and arrest in ferritic steel

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## ABSTRACT

Structure integrity analysis generally assume that it is sufficient to prove that crack initiation will not occur at a particular defect, in every situations including the most severe one. Nevertheless, in order to extend the nominal service-life of some facilities as the nuclear power plant, more and more elaborate studies may be considered, including for example the possibility of crack arrest after its hypothetic initiation. To improve the understanding and the ability to model dynamic crack propagation, both advanced numerical methods and analytical experiments are needed.

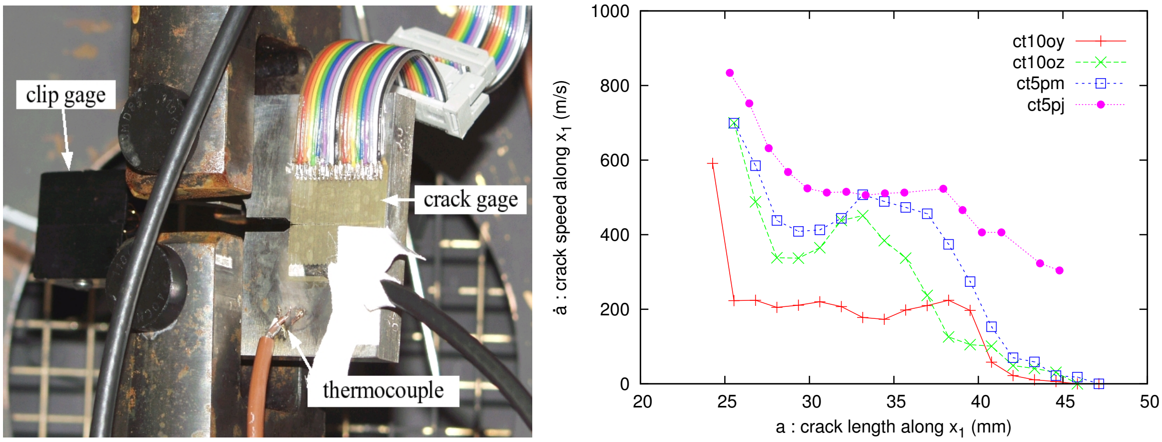
The eXtended Finite Element [1] has two main features. First, the crack geometry is not described by the mesh, but by a couple of level set functions. Then, the displacement approximation is enhanced by adding to the usual shape functions $N_i$ discontinuous $H$, and singular $F_j$ funtions describing accurately the crack influence. They imply that the numerical integration of enriched elements must be done with caution. We therefore used a non-conforming method of sub-division described in [2]. This enables accurate and straightforward integration of enriched elements, and it avoids the projection of mechanical fields (stresses and strains) into a high-gradient zone (the crack tip). In addition, the technique of level set function updating in an auxiliary grid described in [2] is used.

This modern numerical method has been developped in the finite element software Cast3M [3]. Its efficiency to propose, identify and validate cleavage crack propagation models in PWR ferritic steel is demonstrated in this article and in [4]. The methodology is based on two steps.

The first step consists in using the results of experiments on conventional laboratory specimens (Compact Tension made of ferritic steel 16MND5 (A508)) in numerical simulations to calibrate crack propagation criteria. Experimental crack length evolution with time is imposed to CT to find out a parameter driving crack propagation.

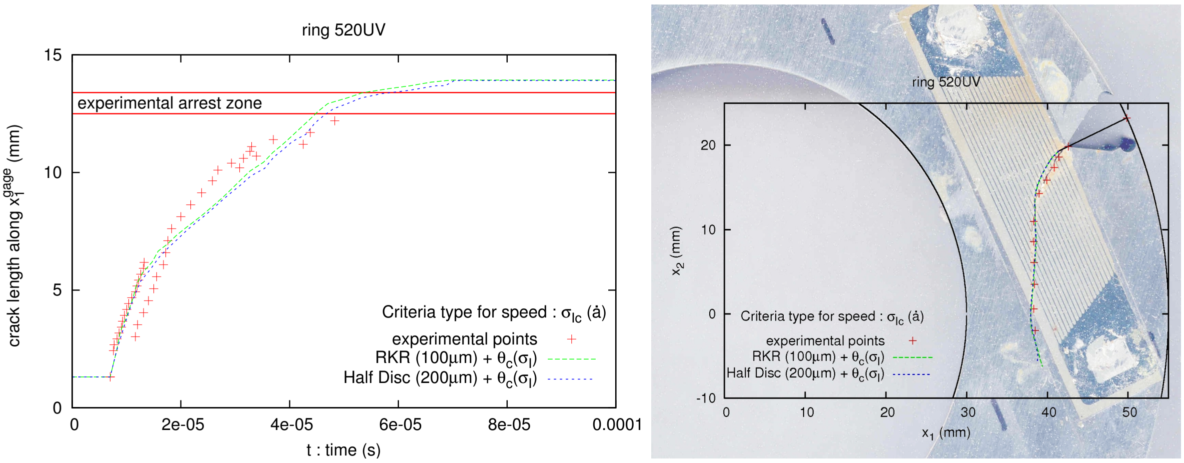
These simulations are used to determine models of propagation based on the principal maximum stress calculated in the vicinity of the crack tip (at a precise point as the RKR model suggests it, or by an averaging technique). A key aspect of this model is the critical cleavage stress dependence with either crack speed or strain rate.

$$\sigma_I^{tip}(\underline{\underline{\sigma}}, \underline{x}) \;=\; \sigma_{Ic}(\dot{a} \text{ or } \dot{\epsilon}) \qquad (1)$$



*Experimental device (left) and crack speed measurement (right)*

Then, as a second step, these calibrated models of propagation are used in numerical simulations to predict crack propagation for different specimens, including not only CT, but also rings specimens in both mode I and mixed mode. The comparison with experimental data of the crack speed, arrest and path obtained with predictive simulation proves the relevance of the model of propagation proposed. Example of predictive results obtained in mixed-mode case is given in the following figures.



*Comparison of predictive simulations with experimental results*

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