X-FEM and explicit crack meshing techniques applied to industrial fracture mechanics problems

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Over the past decades, the finite element method has been one of the most popular tools for computational mechanics in engineering. Applied to the specific field of fracture mechanics, such techniques have suffered for a long time from limitations that make them difficult to use in an industrial framework. Complex issues are mainly related to the specific remeshing effort required to properly model an evolving crack geometry and the singular phenomena arising in the front vicinity. Recently, a considerable effort of the computational mechanics community has been devoted to find solutions to these drawbacks that were generally prohibitive for industrial use.

On one side, alternative techniques such as meshless methods, boundary element methods, or partition of unity derived methods have been highly investigated. Among the last category, the extended finite element method (X-FEM) is becoming particularly popular in the industry. By introducing enriched finite element shape functions, this technique avoids some of the drawbacks mentioned above. Moreover, due to its FEM basis, the X-FEM can be implemented with a relatively low intrusive level within finite element codes. However, in large or complex structures, initial mesh adaptation is still needed since elements of a reasonable size are required in the crack area.

On the other side, recent improvements of meshing and remeshing techniques allow the generation of 3D meshes with an explicit representation of the crack surface even for complex geometries. Such an effort, on the meshing and remeshing step, now give the ability for usual finite element method to be applied to complex industrial fracture mechanics problems.

In this work, we intend to treat some of the benchmark tests proposed by the mini-symposium organizers using both the X-FEM and a robust crack conform FEM strategy. The purpose is to compare the two approaches in terms of accuracy, robustness and computational cost and to show that both are suitable for industrial applications. The computations will be performed with the Z-Set finite element software co-developed by the École des Mines de Paris, NW Numerics and ONERA. The X-FEM and the state-of-the-art meshing technique previously mentioned are both available in this software.

The X-FEM have been implemented in Z-Set at a relatively low intrusive level by properly using the C++ object oriented layer of the code [?]. To deal with multiscale structural aspects, an automatic non-conform mesh refinement is performed at the crack vicinity. Starting from an initial uncracked discretization, it is therefore possible. The crack geometry is handled by level sets discretized on an auxiliary structured mesh and are updated with classical finite difference schemes [?]. Level sets can be used for pre-treatment, for post-treatment, but also to define the aforementioned mesh refinement area since structure and level sets discretization is independent.

The new explicit crack remeshing process is also based on an uncracked adaptative finite element mesh linked to a surface mesh representing the crack. In order to lead computations on cracked meshes,
a robust intersection technique has been developed: the uncracked mesh is first refined in the crack area, then, in the same way the X-FEM elements are cut, the discontinuous surface is generated using the intersecting edges of the volume mesh. Finally another remeshing process is carried out in order to generate a good quality explicit finite element mesh, refined in the crack vicinity.

The stress intensity factors extraction is carried out through a G-θ based procedure[?]. The energy release rate is computed using an analytic derivative formulation taking into account residual stresses, thermal strain or volume forces even applied near the crack front. For isotropic mechanical behaviors a classical interaction integral has also been implemented. Non-planar crack growth directions can be predicted using a maximal tangential stress criterion or a maximal energy release rate criterion. The whole crack growth simulation process can also be associated to an implicit strategy[?] with a free choice of the discontinuity representation method (X-FEM or explicit mesh).

![Figure 1: 3D crack growth simulation during a turbine disc failure analysis.](image)

These techniques have already been applied to some complex 3D cracked structures (cf. figure ??) and will be used to treat some of the proposed benchmark tests, in order to validate their accuracy, robustness and computational cost.

References


