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A multigrid X-FEM strategy for 3-D fatigue crack growth simulation

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ABSTRACT

The extended finite element method (X-FEM) is now a widely used technique, especially in fracture mechanics. Due to their intrinsic multiscale nature, applications to real industrial problems still need to be improved. Several scale can indeed be exhibited in such problems. The scale of the whole structure can be analysed with classical finite element techniques. The scale of the crack, wich can differ from several order of magnitude from the previous one, can be locally analysed by the use of extended finite elements. For fatigue crack propagation, nonlinear phenomenons in the crack tip area (confined plasticity), or along the crack faces (contact, friction, etc) have also to be considered. Several works aiming at handling those different scales in the X-FEM framework have been recently published [1,2]. In the present work, we propose a new method based on local multigrid techniques that offers both a robust handling of the different scales and a high efficiency in the cpu time point of view. Applications to three-dimensional fatigue crack problems are presented. Different key points dealing with crack description with level sets within this multiscale framework as well as the stress intensity factors computation are emphasized. Comparison with experimental data are finally provided to highlight the good accuracy of the method.

Multigrid techniques have been introduced in the seventies as an efficient solver for elliptic problems. They are the one of the most efficient techniques to solve large linear problems. Multigrid solvers basically use several meshes of different discretization levels to improve the convergence rate. An extention to these aspects is here applied to the X-FEM. Relatively coarse meshes are used to model the whole structure with classical finite elements while local fine patches are used to model the crack with X-FEM enrichments. The communication between the different meshes is performed by the use of intergrid operators that transfert primal or dual quantities from one scale to an other. The algorithm is derived from the principle of virtual work [3]. This tool provides an easy way to handle the different scales with their respective physical models and keeps the good convergence properties of the multicale strategy.

This tool is then applied to three-dimensional fatigue crack growth. Several aspects of the computation are of big importance to solve accurately such problems. On one hand, the crack geometry needs to be correctly described. This is done by the use of an auxilliary level set discretization where all operations (propagation, gradient computation to determine local bases along the front) are performed within the finite difference framework. One direct consequence is the front definition improvement. On the other hand, the stress intensity factors computation (SIFs) has also to be accurate since it governs the propagation itself through the use of a Paris' propagation law. Classical interaction integrals are used and a parametric study of the size of the integration domain as well as the influence of the virtual crack extension (VCE) field are presented. Specific VCEs have also been implemented to alleviate some numerical problems on the SIFs computation near free surfaces.

Numerical results are finally compared to experimental data. An elliptic crack in a fine grain aluminum sample is submitted to fatigue cycles. X-ray microtomography scans of the sample are regularly performed and the crack geometry is then extracted by appropriate image treatment techniques[4].

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