Efficient prediction of 3D crack propagation using configurational forces

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In many applications, the 3D propagation of a crack is of great interest. This propagation can be predicted in FEM models either by using damage of the material or element (phase-field models), by special elements that can contain cracks (XFEM), or by discrete modeling of the crack and using classical fracture-mechanical approaches to compute the Crack-Driving Force (CDF) [1]. In CDF-based approaches, the crack is repeatedly extended by a crack increment.

The physically-based concept of Maximum Energy Release Rate (MERR) is assumed to be the most general criterion for crack propagation, which can be evaluated using trial and error by introducing a range of virtual crack extensions. The direction with the highest energy dissipation yields the crack propagation direction.

One widely used measure of the CDF is the J-integral, which has been extended using configurational forces to also be valid for non-proportional loading and inhomogeneous materials [2] and yielding a vector of the CDF. The configurational force corresponds to the gradient in potential energy for a change in geometry. It yields non-zero values at inhomogeneities such as interfaces, surfaces, and cracks. For cracks, however, this J-integral vector is only valid for a crack propagation in the same direction as the previous crack propagation direction. For a curving crack path, the configurational-force-based J-integral only approximates the crack driving force. Small crack increments are therefore needed for highly curved cracks.

By introducing a virtual crack extension and evaluating configurational forces for that crack, the accuracy of the direction to meet MERR of that virtual crack extension can be evaluated, based on the meaning of configurational forces. Therefore, the authors have developed a method that evaluates the nodal configurational forces in a FEM mesh and uses them to repeatedly correct the crack angle of the virtual crack in 2D structures [3]. This method is nearly as accurate as trial and error but much faster. Also, the method is much more accurate than directly using the J-vector for crack extension with only a slight increase in computational effort.

For 3D cracks, using trial and error an enormous computational effort is necessary to find the crack propagation direction for MERR. Such high computational effort is usually uneconomical. Therefore, in this work, the repeated crack correction concept is extended to 3D cracks and evaluated for simple cases from literature [4]. In 3D, our tool computes the direction of MERR with manageable effort for the same accuracy as trial and error. Due to the material-independent formulation of configurational forces, it is ready to be extended towards heterogeneous materials and elastic-plastic materials.

References

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