A cohesive XFEM model for simulating fatigue crack growth under in-phase and out-of-phase mixed mode loading and overloading

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ABSTRACT

Numerous structures such as wind-turbines, bridges and aeroplanes are exposed to fatigue loading. Fatigue crack growth is often studied for constant amplitude mode I loading cases. However, such cases do not represent real-life scenarios in which the direction, magnitude and order of the applied loads are changing constantly. A new fatigue crack propagation model is presented which allows to capture the effects of in-phase and out-of-phase mixed-mode loading and overloading, enabling simulations that closer represent actual fatigue load applications.

The presented model is built upon the phantom-node version of the extended finite element method (XFEM), which enables a crack to grow in arbitrary direction independent of the mesh geometry. The model makes a distinction between a physical crack tip and a numerical one. In between the two tips, ahead of the physical tip, a cohesive zone is implemented that represents the gradual failure of the material. The tractions in this cohesive zone follow from a bilinear cohesive law with the addition that damage is set to one behind the physical crack tip. Both crack tips have their own criterion for propagation. Numerical crack tip propagation occurs once the maximum principal stress around the tip exceeds a threshold stress. The crack growth direction is defined to be perpendicular to the non-local maximum principal stress. To allow for high-cycle fatigue analysis, a cycle jump strategy is employed where after every computed cycle the physical crack tip propagates through one element while the actual number of cycles required for this crack increment is determined from the energy release rate (ERR) with Paris' equation. The bulk material behaviour is modelled using cyclic plasticity relations. The model requires calibration of the cohesive zone parameters to a mode I overload case to control the amount of plasticity around the crack tip.

The model is validated against experiments for in-phase and out-of-phase mixed-mode loading and overloading. Reasonable agreement with experimental observations is found in terms of both crack growth rate and crack growth direction for all studied scenarios.