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PRECISE SIMULATION OF 3D FATIGUE CRACK PROPAGATION

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ABSTRACT

The simulation of 3D-fatigue crack propagation in terms of linear elastic fracture mechanics is presented. Due to the nonlinear behavior of crack growth an incremental procedure has to be applied. Special attention is focused on the continuous change of the stress field within the incremental procedure. In each increment three steps have to be performed: **a)** a complete stress analysis including the calculation of the relevant fracture mechanical parameters (stress intensity factors (SIFs), T-stresses), **b)** the evaluation of the 3D crack growth criterion and the determination of the new crack front and **c)** the update of the numerical model.

The 3D dual boundary element method (DUAL BEM) [1] is applied for the computation of the stress field. Within this method especially suitable for crack problems additionally the hyper-singular traction boundary integral equation is taken into account. The fracture mechanical parameters are accurately extrapolated from the stress field by a regression analysis optimized by the minimization of the standard deviation [2].

The crack deflection as well as the crack extension for every point P along the crack front have to be determined to define the new crack front relative to the current one. The maximum tangential stress (MTS) criterion has been established for the calculation of the kink angle. It is extended by the utilization of the T-stresses in order to consider the curvature of the crack path. In the present context the cyclic equivalent SIF ΔK_{eq} is determined by the criterion of the maximum energy release rate [3]. By the evaluation of a crack propagation rate formulation

$$\Delta a(P) = \frac{\mathrm{d}a}{\mathrm{d}N}\Big(\Delta K_{eq}(P)\Big)\Delta N_{lc} \tag{1}$$

the local crack extension $\Delta a(P)$ is predicted in a linear way. In this equation ΔN_{lc} denotes a user-defined prescribed number of load cycles.

Since the fact of a changing stress field between the initial and the new crack front is not included in the predictor step, corrector steps are required. Within the next incremental loop the cyclic equivalent SIFs for all points of the new crack front are additionally known. By using this knowledge, the stress field between these two crack fronts is approximated and a more accurate number of load cycles ΔN_{acc} is recalculated, which differs from the prescribed number ΔN_{lc}. Therefore, the new crack front is

corrected in such a way that the accurate number of load cycles ΔN_{acc} converges to the prescribed one. To demonstrate the benefit of the presented predictor-corrector scheme a 4-point bending specimen of the transparent material PMMA with a complex initial crack front is chosen, cf. Fig. 1a and b. This initial crack front has been formed by simple mode-I loading conditions within experimental

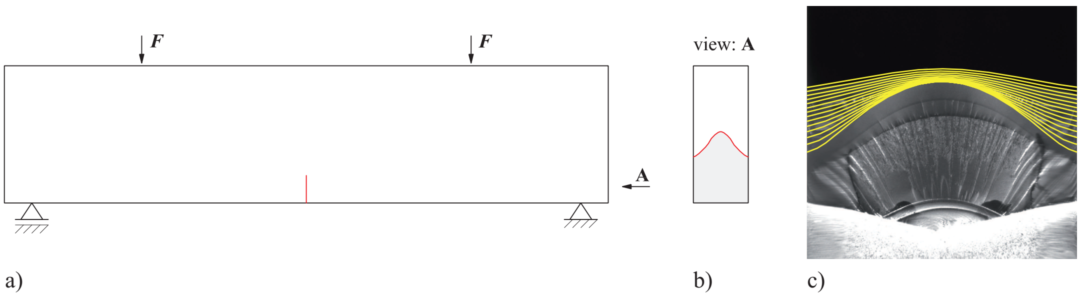

Figure 1: Four-point bending specimen with complex initial crack front

investigations [4]. The strong curvature of the crack front is caused by a state of residual stress in the specimen. Then, the residual stresses have been reduced by tempering the specimen just below the glass transition temperature. Afterwards, the crack only propagates in the vicinity of the free surfaces, which is a real challenge for the simulation.
The crack fronts sketched in Fig. 1c are obtained by the application of the presented predictor-corrector scheme. Here, the prescribed number of load cycles N_{lc} has been set to 10000 and the crack propagation rate formulation [4]

$$\frac{\mathrm{d}a}{\mathrm{d}N} = \frac{C(\Delta K_{eq} - \Delta K_{th})^m}{(1-R)K_C - \Delta K_{eq}} = \frac{10^{-4}(\frac{\Delta K_{eq}}{MPa\sqrt{mm}} - 11)^{0.91}}{(1-0.5)50 - \frac{\Delta K_{eq}}{MPa\sqrt{mm}}} \tag{2}$$

is utilized. In the vicinity of the lower threshold value small variations of the cyclic equivalent SIF lead to a wide difference of the crack propagation rate, which is considered in the presented predictor-corrector scheme. Moreover, the parts of the crack front which start growing between two successive crack fronts can be detected. At such a part the crack front is approximated by a cubic spline to prevent non-physical stress concentrations within the next incremental loop.
Overall, a good agreement between the numerical obtained crack fronts and the experimental results can be observed.

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