Configurational Forces in Three-Dimensional Crack Loading Analyses and Crack Growth Simulations

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Abstract: In order to evaluate cracks in three-dimensional (3D) specimens, it is necessary to perform crack loading analyses. Loading quantities are calculated, employing the distribution of stress and strain in the vicinity of the crack front. In thin planar structures with plane mode I/II loading, analyses at simplified two-dimensional boundary value problems provide sufficiently accurate loading quantities. However, for an increasing thickness or presence of mode III loading, the plane assumptions in general lose their validity. Three-dimensional structures exhibit spatial stresses, leading to a non-constant stress distribution along the crack front and to non-uniform crack front loading, respectively. As a result, cracks grow in tongue-like shapes or even twist while growing, which cannot be taken into account without solving the three-dimensional boundary value problem. A well-known loading quantity for three-dimensional analyses is the J-integral, which Rice and Cherepanov introduced independently in the late 1960s. Often equivalent domain integrals are applied for the calculation of J in a finite element (FE) framework. Scalar values of J, related to virtual crack extension areas along the crack front, are obtained, while information on the direction of local crack propagation is not directly provided in terms of a J-integral criterion. However, configurational forces in the material space, which are strongly related to the J-integral vector, provide both loading quantity and crack propagation direction, and were implemented to perform crack growth simulations. This work focuses on the calculation of three-dimensional configurational force vectors and their application to 3D crack growth simulations. Therefore, criteria for crack propagation and crack deflection are developed and implemented into a commercial FE code. Due to an incremental crack propagation approach, an intelligent remeshing strategy is applied to ensure high accuracy of the configurational forces in connection with small computational times. The calculated three-dimensional crack paths are compared to experiments.