Prediction of the growth rate and propagation direction of fatigue cracks with the configurational forces model

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The concept of configurational forces is a powerful computational tool for the quantitative description of the behavior of defects in materials and structural components. It enables us

(1) to evaluate the crack driving force in arbitrary micro- or macroscopically inhomogeneous materials and components,
(2) to take into account the influences of eigenstrains and residual stresses,
(3) to assess the shielding and anti-shielding effects of near-tip and remote plasticity,
(4) to estimate the crack growth direction using the criterion of maximum dissipation.

In this presentation, first a short overview shall be given about theory and computational aspects. Then two specific applications are shown where the growth rate and propagation direction of fatigue cracks is predicted with the configurational forces model. The specimens are diffusion welded bimaterial specimens made of soft ARMCO iron and a high-strength steel SAE4340. The stress intensity range ΔK was held constant during the crack growth experiments.

The local crack driving force vector J_{tip} is evaluated as a vector sum of the far-field J-integral vector J_{far} and the so-called material inhomogeneity term vector, C_{inh}. The latter term quantifies the crack tip shielding or anti-shielding effect of the material inhomogeneities. The crack driving force is determined from the magnitudes of J_{tip} at the maximum and minimum load of a load cycle, either with or without taking into account the effects of crack closure. The direction of the J_{tip}-vector yields the direction of the crack extension step, in accordance with the criterion of maximum energy dissipation. The values of the J-integrals and the material inhomogeneity term are computed by a post-processing procedure after a conventional finite element stress analysis.

In the first example, the interface is perpendicular to the crack plane. In the second example the interface normal exhibits an angle of 30° to the crack plane, causing a deflection of the crack from the initial crack plane. The numerical predictions are compared to the experimental results.

It is demonstrated that in both examples, the behavior of the cracks can be described quantitatively without use of any fit parameter. The residual stresses, which appear due to the slightly different coefficients of thermal expansion, have a large effect on both crack growth rate and crack growth direction. Still unsolved are questions about the correct modeling of the crack closure behavior and the unknown direction dependency of the crack growth velocity, which is important for the application of the criterion of maximum dissipation for the evaluation of the crack propagation direction.