LEFM based criterion for crack propagation under complex structural loadings

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Historically, Linear Elastic Fracture Mechanics (LEFM) based criteria rely on either stress intensity factors (SIF) or energy release rate. For 2D structures under quasi-static loading, one has to decide if the crack propagates or not and if yes in which direction. Concerning crack propagation, the classical criterion is the Griffith's criterion. It is a kind of unilateral relationship based on the positiveness of the dissipation, meaning the crack propagates if the energy release rate reaches its critical value G_c (defined as a material property) and that the energy release rate should remain at the critical value all along the failure process, the crack velocity being adjusted so that this condition is met. Concerning crack orientation, many criteria exist either based on the max hoop stress, the maximum energy, the symmetry of the loading.....In 3D, the problem is slightly more complex as the condition defined above cannot be met all along the crack front and one has to define the crack velocity profile based on SIF or energy release rate distribution along the crack front.

However, while there is a kind of consensus on the universality of this criterion and the definition of G_c, it has been shown by several authors that, even for a material like PMMA considered as a model material for brittle fracture, this criterion fails at predicting crack propagation for some specimen geometries [1, 2]. In other words, the stress field induced by structural effects (geometry, loading) and through which the crack is propagating has an influence on G_c. This is usually named 'constraint effect'. Nonlocal models using an smoothed description of the crack discontinuity (like phase field, non-local damage, micro-morphic damage,...) have the ability to handle this kind of situation. This is due to their internal length parameter allowing for the model to probe the material in a finite volume at the crack tip. The limitation of LEFM based criteria is thus due to their local nature, probing the material only at the crack tip through SIF. But, their much lower computational cost make them the best candidate for structural application, inducing loading for which they fail at being predictive. Elaborating *non-local* LEFM criteria is thus of huge practical importance.

Based on experimental direct estimations of SIF and higher order terms in the asymptotic expansion of the linear elastic field around the crack tip (T-stress T, B-stress B), we suggest and calibrate a stress based criterion. This criterion relies on the estimation of the stress tensor at a distance r_c of the crack tip from SIF, T and B. The two parameters of this criterion are the critical distance or internal length r_c and the critical stress σ_c. Compared to existing *generalised* LEFM criterion, our criteria is: based not only on SIF and T but it relies also on B, based on the second invariant of the stress tensor, as the usually adopted maximum tensile stress cannot account for the influence of T for pure mode I straight crack propagation, calibrated using direct experimental estimation of SIF, T, B from full-field displacement measurements (implemented in [3]) instead of using finite element models.

This formalism is convenient as the critical stress σ_c (or the fracture toughness K_{Ic}) are estimated independently on the structural effects, these effects being accounted for by the criterion itself. Based on the same idea, a generalised energy criterion can be formulated allowing for capturing even more complex situations. For validation purposes, the prediction of these criteria implemented using X-FEM is compared to the results of a validation experiment.

References

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