Validated model for predicting crack initiation from arbitrary-shaped notches

M. Rettl*, M. Pletz, C. Schuecker

Designing Plastics and Composite Materials, Department of Polymer Engineering and Science, Montanuniversitaet Leoben, Otto-Gloeckl Strasse 2, 8700 Leoben, Austria, matthias.rettl@unileoben.ac.at

In engineering, it is often asked what is the maximum load a component can withstand before it fails. The coupled criterion [1, 2] was introduced to predict the failure from notches accurately. It combines a stress- and an energy-criterion. At a position at which both criteria are fulfilled simultaneously a crack will initiate and failure will occur. One drawback is that the energy-criterion requires the incremental energy release rate which has only an analytical solution for very simple notch geometries like V- and U-notches.

To compute the incremental energy release rate for an arbitrary-shaped notch the Finite Element Method (FEM) can be used. If the failure should be predicted at all positions on a notch, virtual cracks are introduced sequentially all along a notch surface in an FEM model and the incremental energy release rates are computed from the deviation of the strain energies. Since, for each position on the notch several simulations with various crack lengths are performed, this approach is computationally intensive.

The authors developed an efficient two scale approach to apply the coupled criterion all along a notch surface [3]. The larger component scale utilizes a FEM analysis and provides the displacement- and force-field. The local model provides the incremental energy release rate and is parametrized by two dimensionless quantities. This allows to scale the local model and use it for materials of various stiffnesses. The local model is computed in advance for various virtual crack lengths and for five deformation modes that are used to fit the forces and displacements of the component model with the help of linear superposition. Furthermore, the local model approximates the local curvature of the notch by a quadratic function. However, since the local model behaves similar to a submodel with fixed boundary conditions, the energy release rate is underestimated if cracks are introduced. Therefore, automatically weighted force- and displacement-controlled boundary conditions can be used. Those boundary conditions allow a deformation during the opening of virtual cracks. That makes the prediction of the incremental energy release rate more accurate.

Our two-scale approach has the disadvantage that for some geometry and material combinations the initiation length of a crack is longer than the size of the local model. In this case no prediction is possible.

The goal of this work is to define where our approach works and under which circumstances it is essential to use the coupled criterion, because a stress-based criterion gets too inaccurate. Therefore, experimental tensile tests of specimens containing various notches are provided. Furthermore, the maximum load is predicted using a stress-based criterion as well as the coupled criterion.

References

[1] D. Leguillon, Strength or toughness? A criterion for crack onset at a notch, Eur J Mech-A/Solids 21.1 (2002): 61-72.

[2] P. Cornetti, et al., Finite fracture mechanics: a coupled stress and energy failure criterion. Eng Fract Mech 73.14 (2006): 2021-2033.

[3] M. Rettl, et al., Efficient prediction of crack initiation from arbitrary 2D notches. Theor Appl Fract Mech 119 (2022): 103376.