Embedded Discontinuity Finite Element Method (ED-FEM) for Modeling Fiber Failures in Random Fiber Networks

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ABSTRACT

Paper materials are natural composite materials where fibers are almost randomly distributed in a fiber network. Mechanical properties of fiber networks are known to be strongly controlled by fiber-fiber interactions and single fiber properties. A fiber network is often modeled as a beam network where beam-to-beam interactions are treated as cohesive zones and single beams stretch indefinitely without breaking. The latter assumption is not physically correct and leads to an overprediction of the mechanical response of the beam network. In this work, we present a computational modeling framework for simulating beam failures and thereby closing the gap to physically based micromechanical modeling of paper and packaging products.

Modeling beam failure is a challenging engineering problem. At the onset of failure, the tangent stiffness tensor projected in a direction normal to the surface of discontinuity (commonly referred to as the localization tensor) is singular, i.e. we have a bifurcation point and the problem is ill-posed. Another implication of ill-posedness for the numerical simulation after a spatial discretization is a pathological mesh dependency of the computed result.

We use the ED-FEM where a failure process zone (FPZ) is introduced into a multi-scale continuum mechanics formulation (i.e. the material is split into a small scale and a large scale defining the FPZ and the bulk material, respectively), making the computed result mesh independent. The multi-scale nature of the ED-FEM enables an operator splitting implementation method as opposed to carrying out the computations of the nodal displacement vector and the displacement discontinuity vector simultaneously with the global loop where the global stiffness matrix would be singular at the onset of failure.

We show that fiber failures and fiber-fiber bond failures can contribute to the observed elastoplastic stress-strain response of paper.