A Cohesive Model for Mixed-Mode Delamination with Transition to Fiber Bridging

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ABSTRACT

In several different types of composite materials, after initial decohesion interfaces exhibit additional resistance resources due to crack bridging, which can be activated when large openings take place. Depending on the nature of the interface and of the joined materials, these additional strength mechanisms can be due, e.g., to fibrillation or fiber bridging and can account for a large share of the final interface strength. However, when large openings or extensive fiber bridging phenomena are involved, classical cohesive models formulated under the assumption of small relative displacements usually fail to correctly predict the delamination growth. It is well known that rotational equilibrium is not guaranteed in cohesive models in the presence of large openings [1], while the activation of large-scale fiber bridging mechanisms sensibly increases the interface fracture energy [2], described in terms of R-curves, which does not remain constant, expressing the progressive toughness growth. This effect is mainly governed by the normal opening and is promoted by the available mode I energy, as it has been experimentally observed in several DCB tests performed on fiber-reinforced composites.

In this work, the isotropic damage cohesive model formulated in [3] under the assumption of small openings is extended to account for large openings and for the presence of large-scale bridging or interfacial fibrillation. The considered cohesive model is particularly suited to treat mixed-mode delamination with variable mode ratios, since no a-priori assumptions are made on the shape of the failure locus in terms of fracture energy, and it allows for different forms of the traction-separation law in the pure modes.

Based on the experimental observation that fiber bridging is mainly induced by Mode I loading, two distinct traction-separations laws are introduced for Mode I and II. A standard bilinear traction-separation law in pure Mode II and a trilinear form in pure Mode I, consisting of an initial linear branch, followed by a bilinear softening branch. The transition from small to large openings with the onset of the bridging mechanism is described by replacing the classical interface element with a fibril element, endowed with a constitutive behavior such that no discontinuity in the dissipated energy or in the transmitted cohesive tractions is introduced. As shown in [1], fibril elements of this kind are able to account for large openings without loss of rotational equilibrium, since the interface tractions and openings are colinear.

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