Mixed-Mode cohesive model with tensile frictional interaction for the simulation of delamination.

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Interface elements based on cohesive formulations provide an effective numerical tool for the simulation of the decohesion processes occurring during delamination and debonding phenomena. Although a large number of cohesive models has been proposed in the literature, many of them exhibit limitations or drawbacks in dealing with mixed-mode loading conditions with variable mode ratios. Accurately predicting the delamination growth requires the cohesive law to respect some basic thermodynamic requirements, such as producing a positive dissipation under any loading path, to properly describe the mode interaction, and to correctly reproduce the experimentally measured dissipated energy under any loading path. Several experimental studies point out that the fracture energy significantly increases in passing from pure Mode I to pure Mode II [1].

A new cohesive model, specifically conceived for the description of mixed-mode delamination and based on an isotropic damage formulation, is proposed in this this paper. The interaction between tensile normal and shear behavior is governed by a three-surface activation domain defined in the plane of dimensionless cohesive tractions by means of the introduction of an internal friction coefficient. This activation domain allows for the definition of three different damage modes, namely two shear dominated frictional modes and one opening mode, each one identified by a surface of the activation domain. The overall strain energy release rate is additively decomposed according to the introduced damage modes.

Two different shapes of the softening branch are considered in this work: namely, a classical linear one and an exponential one, derived from the inelastic potential proposed in [2].

The proposed model has been proven to be thermodynamically consistent for any loading path, also in the case of not constant mode ratio. In addition, it is able to capture the variation of the overall fracture energy (i.e. the dissipated energy at complete decohesion) at increasing mode ratios without the need to introduce an *ad hoc* empirical criterion.

Classical delamination tests, such as the Double Cantilever Beam (DCB), the End-Notch Flexure (ENF) and the Mixed-Mode Bending test [3], are simulated to assess the accuracy of the numerical predictions. The numerical results are in good agreement with the experimental data in the case of both pure and mixed mode delamination.

References

*[1] Benzeggagh, M. L., and Kenane, M., "Measurement of mixed-mode delamination fracture toughness of unidirectional glass/epoxy composites with mixed-mode bending apparatus", Composites science and technology, **56**, page 439-449, (1996).*

*[2] Comi, C., and Perego, U., "Criteria for mesh refinement in nonlocal damage finite element analyses", European Journal of Mechanics - A/Solids, **23**, page 615-632 (2004).*

*[3] Reeder, J.R., and Crews, J.H., "Mixed-mode bending method for delamination testing", AIAA Journal, **28**, page 1270-1276 (1990).*