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A smooth cohesive law for mixed-mode delamination

Federica Confalonieri* **and Umberto Perego***

* Department of Civil and Environmental Engineering
Politecnico di Milano
Piazza Leonardo da Vinci, 32, 20133 Milano, Italy
e-mail: federica.confalonieri@polimi.it; umberto.perego@polimi.it

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ABSTRACT

Delamination, i.e. the decohesion between layers, is one of the main failure modes in composite materials. Making use of robust and accurate numerical tools is fundamental to reliably predict the delamination growth. The finite element simulation of these problems is often dealt with by the insertion between adjacent layers of interface elements, whose constitutive behavior is described by a cohesive model in terms of a traction-opening displacement law. In the literature, there exists a variety of works devoted to the formulation of cohesive laws (see [1] for a comparative review of some models), although many of them exhibit a number of shortcomings, such as the need of strong assumptions on the loading path and on the mixed-mode failure properties, or the lack of thermodynamic consistency. Real-life delamination processes are indeed often characterized by mixed-mode loading conditions with varying mode ratio. In addition, several experimental results show that the fracture energy significantly grows in passing from pure Mode I to pure Mode II [2].

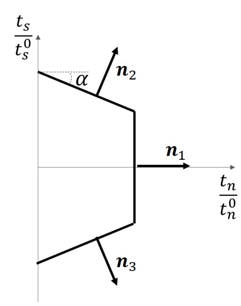

Figure 1: Three-surface activation domain.

This work presents a new cohesive model, specifically conceived for mixed-mode delamination. The model is based on an isotropic damage formulation, that ensures its thermodynamic consistency for any loading path. The interaction between normal and tangential openings is modeled by introducing a three-modes activation surface, of the type shown in Fig. 1, defined in the plane of dimensionless cohesive tractions. Each normal defines a distinct damage mode, namely one opening and two shear-dominated modes. The shape of the domain depends only on the angle of inclination of the two shear dominated modes, which acts as a parameter of internal friction in the presence of positive normal tractions. The projection of the cohesive tractions onto the three normals allows for a decomposition of the strain energy release rate in terms of the contributions of the three damage modes.

The overall fracture energy is an outcome of the interaction between damage modes, without the need of introducing any empirical law. As an example, Fig. 2 shows the growth of fracture energy as a function of the mode-mixity ratio for a AS4/PEEK carbon-fiber-reinforced composite (see [3]). The light dashed curve reports the numerical result of the present model, the dark one the widely used empirical Benzeggagh-Kenane (BK) law [2], while the square dots are experimental points resulting from Mixed-Mode Bending tests [4]. It can be noted that the proposed model is able to adequately reproduce the transition from pure Mode I to Mode II in terms of dissipated energy at complete decohesion.

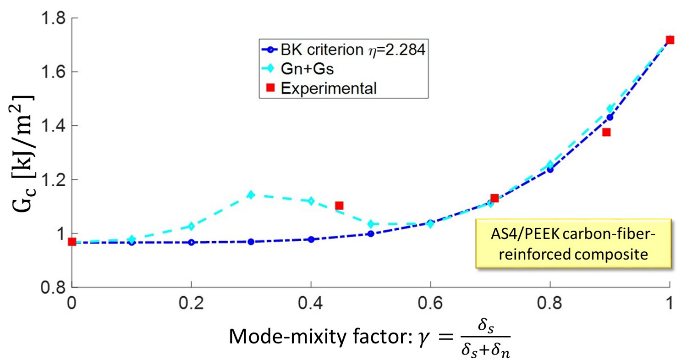

Figure 2: Mixed-mode fracture energy vs mode-mixity parameter.

An exponential softening branch, deriving from the inelastic potential proposed in [5], is introduced in order to allow for a more accurate fitting of experimental data and to reduce the oscillatory response in the case of explicit dynamic analyses.

The proposed cohesive model has been validated on several benchmark tests available in the literature, mainly focusing on Mixed-Mode Bending (MMB) tests [4].

REFERENCES

[1] R. Dimitri, M. Trullo, L. De Lorenzis, G. Zavarise. Coupled cohesive zone models for mixed-mode fracture: A comparative study. *Engineering Fracture Mechanics*, **148**:145-179, 2015.

[2] M.L. Benzeggagh, J.H. Crews. Measurement of mixed-mode delamination fracture toughness of unidirectional glass/epoxy composites with mixed-mode bending apparatus. *Composites Science and Technology*, **56**:439-449,1996.

[3] P.P. Camanho, C.G. Davila, M.F. de Moura. Numerical Simulation of Mixed-mode Progressive Delamination in Composite Materials. *Journal of Composite Materials*, **37**:1415-1438,2003.

[4] J.R. Reeder, J.H. Crews. Mixed-mode bending method for delamination testing. *AIAA Journal*, **28**:1270-1276,1990.

[5] C. Comi, U. Perego. Criteria for mesh refinement in nonlocal damage finite element analyses. *European Journal of Mechanics A/Solids*, **23**:615-632,2004.