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A Critical Review of Traction-Separation Relationships Across Fracture Surfaces for Cohesive Zone Models of Fracture

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One of the fundamental aspects in cohesive zone modeling is the definition of the traction-separation relationship across fracture surfaces, which approximates the nonlinear fracture process. Cohesive traction-separation relationships may be classified as either nonpotential-based models or potential-based models [6]. Nonpotential-based models are relatively simple to develop, because a symmetric system is not required. However, these models do not guarantee consistency of the constitutive relationship for arbitrary mixed-mode conditions because they do not account for all possible separation paths. For example, a simple linear softening model [2] provides a positive stiffness under softening condition, as shown in Figure 1. In other words, the model results in the increase of cohesive traction when separation increases although such behaviour is not physical.

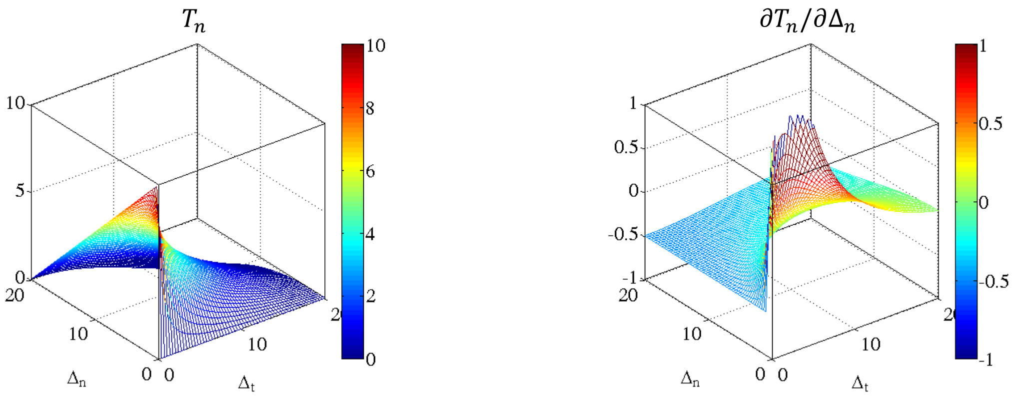

Figure 1: Example of a nonpotential-based model: (a) a linear softening model, (b) the derivative of the traction, which displays an incorrect positive stiffness.

For potential-based models, the traction-separation relationships are obtained from the gradient of a general potential function, which is expressed in terms of normal and tangential separations. A general potential function was introduced by Needleman [3], based on cubic-polynomials for the normal cohesive traction with a linear tangential traction. However, the model is limited for large shear separation. In addition, general potential-based models were developed in conjunction with the universal binding energy [1, 4, 7]. For instance, an exponential-periodic potential-based model [4] was generalized by applying cohesive fracture boundary conditions [1]. In order to account for the complete shear failure condition, the exponential-exponential potential-based model was proposed in reference [7]. However, the exponential-exponential potential-based model possesses several limitations, especially when the mode I fracture energy is different from the mode II fracture energy. Alternatively, a unified potential-based model was derived by the authors from consistent fracture boundary conditions associated with fracture energy, cohesive strength, shape and initial slope [5]. The gradient of the potential is illustrated in Figure 2. However, the aforementioned models still demonstrate several limitations on representing physical phenomena, including fatigue damage, rate dependence, friction, contact, etc. In conclusion, the constitutive relationship of mixed-mode cohesive fracture should be selected with great caution and there is room for further development of such models.

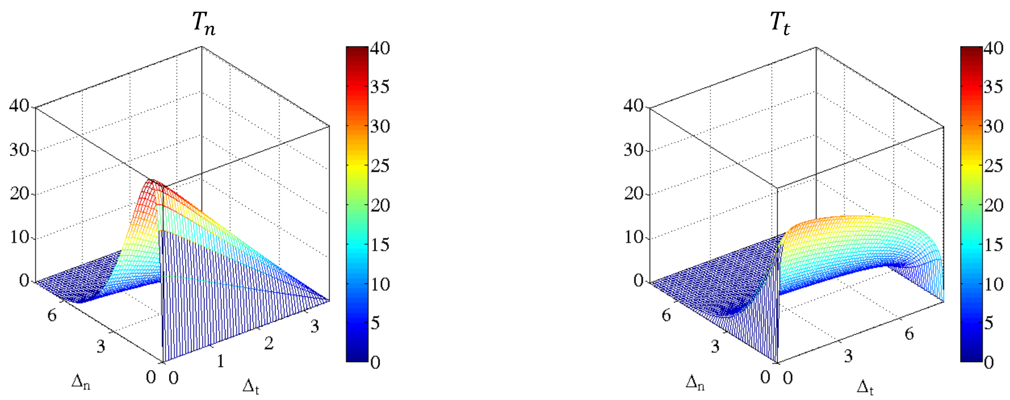

Figure 2: Normal and tangential traction-separation relations of a unified potential-based model

REFERENCES

[1] G.E. Beltz and J.R. Rice, Dislocation nucleation versus cleavage decohesion at crack tips. In: T.C. Lowe, A.D. Rollett, P.S. Follansbee, G.S. Daehn (Eds.), *Modeling the Deformation of Crystalline Solids presented*. Harvard Univ, Cambridge, MA, USA, The Minerals, Metals & Materials Society, pp.457–480, 1991.

[2] P.H. Geubelle and J.S. Baylor, Impact-induced delamination of composites: A 2D simulation. *Composites Part B: Engineering*, Vol. **29**, pp.589–602, 1998.

[3] A. Needleman, A., 1987. A continuum model for void nucleation by inclusion debonding. *Journal of Applied Mechanics - ASME*, Vol. **54**, pp.525–531, 1987.

[4] A. Needleman, An analysis of tensile decohesion along an interface. *Journal of the Mechanics and Physics of Solids*, Vol. **38**, 289–324, 1990.

[5] K. Park, G.H. Paulino, J.R. Roesler, A unified potential-based cohesive model of mixed-mode fracture, *Journal of the Mechanics and Physics of Solids*, Vol. **57**, pp.891–908, 2009.

[6] K. Park and G.H. Paulino, Cohesive zone models: A critical review of traction-separation relationships across fracture surfaces, *Applied Mechanics Reviews - ASME*, Vol. **64**, pp.060802-1–060801-20, 2013.

[7] X.P. Xu and A. Needleman, Numerical simulations of fast crack growth in brittle solids. *Journal of the Mechanics and Physics of Solids*, Vol. **42**, pp.1397–1434, 1994.