On the conditions for pure-mode fracture

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In a *symmetrically* cracked planar body, fracture modes I and II are respectively associated to systems of symmetric and antisymmetric forces w.r.t. the crack plane. These forces respectively produce only normal stresses and relative transverse displacements or only shear stresses and relative tangential displacements on the crack plane. The same pure-mode conditions do not apply in general for *asymmetrically* cracked bodies.

Williams [1] proposed the following pure-mode conditions for an asymmetrically cracked isotropic beam: (i) pure mode I, if the moments of the two sub-beams at the crack-tip cross-section are equal and opposite; (ii) pure-mode II, if the curvatures of the two sub-beams at the crack-tip cross-section are equal. Although questioned [2], Williams' conditions have been used by several authors [3].

Valvo [4] proved that the standard virtual crack closure technique (VCCT) may be inappropriate for analysing problems with highly asymmetric cracks since negative values for either mode I or mode II contribution to the energy release rate (ERR) may be calculated. To remedy this shortcoming, he suggested the following pure-mode conditions: (i) pure mode I, if the tangential crack-tip force is zero; (ii) pure mode II, if the crack-tip opening displacement is zero. Later, Valvo [5] proposed the following conditions instead: (i) pure mode I, if the crack-tip sliding displacement is zero; (ii) pure mode II, if the normal crack-tip force is zero. In both the above proposals, the two pure modes are associated to energetically orthogonal systems of forces, so always non-negative modal contributions to the ERR are obtained. This revised VCCT was then adapted to generally layered beams [6]. Wang and Harvey [7] independently proposed the same energetically orthogonal pure-mode conditions.

This presentation will discuss the various pure-mode conditions proposed, also with reference to experimental tests existing in the literature or to be specifically designed, aiming to clarify which theoretical proposals for pure modes (or mode partitioning) are to be preferred.

References

[1] Williams, J.G.: On the calculation of energy release rates for cracked laminates, *Int. J. Fract.*, 36, 101–119 (1988). DOI: 10.1007/bf00017790

[2] Schapery, R.A.; Davidson, B.D.: Prediction of Energy Release Rate for Mixed-Mode Delamination Using Classical Plate Theory, *Appl. Mech. Rev.*, 43 (5S), S281–S287 (1990). DOI: 10.1115/1.3120829

[3] Shahverdi, M.; Vassilopoulos, A.P.; Keller, T.: Mixed-Mode I/II Fracture Behavior of Asymmetric Adhesively-Bonded Pultruded Composite Joints, *Eng. Fract. Mech.*, 115, 43–59 (2014). DOI: 10.1016/j.engfracmech.2013.11.014

[4] Valvo, P.S.: A revised virtual crack closure technique for physically consistent fracture mode partitioning, *Int. J. Fract.*, 173, 1–20 (2012). DOI: 10.1007/s10704-011-9658-y

[5] Valvo, P.S.: A further step towards a physically consistent virtual crack closure technique, *Int. J. Fract.*, 192, 235–244 (2015). DOI: 10.1007/s10704-015-0007-4

[6] Valvo, P.S.: On the calculation of energy release rate and mode mixity in delaminated laminated beams, *Eng. Fract. Mech.*, 165, 114–139 (2016). DOI: 10.1016/j.engfracmech.2016.08.010

[7] Wang, S.; Harvey, C.M.: Mixed mode partition theories for one dimensional fracture, *Eng. Fract. Mech.*, 79, 329–352 (2012). DOI: 10.1016/j.engfracmech.2011.11.013