Evaluation of the growth driving direction and mode-decomposed energy release rates in arbitrarily shaped delamination fronts

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One of the prevailing failure mechanisms in layered composite structures is the loss of cohesion between constituent layers, known as delamination. In the fracture mechanics approach, delamination growth is usually predicted when the energy release rate, $\mathcal{G}$, equals the fracture toughness, $\mathcal{G}_c$. Two of the most widely used extraction methods for $\mathcal{G}$, are the Virtual Crack Closure Technique (VCCT) [1] and the J-integral [2]. Usually, these techniques are formulated in the framework of linear elastic fracture mechanics, thus assuming a negligible fracture process zone. The mode-decomposition of $\mathcal{G}$ is done according to a local crack coordinate system located on the crack front, such that mode I is normal to the crack surface, mode II is aligned with the propagation direction, mode III is normal to mode I and mode II. The crack propagation direction is usually computed as the normal to the crack front. However, in many cases, such as in quasi-brittle materials, the assumption of a negligible fracture process zone does not apply. The cohesive zone model (CZM) approach can capture the fracture energy dissipation mechanisms occurring ahead of the crack tip before complete separation of the crack faces occurs. In this case, the propagation direction cannot be calculated as the normal to the crack front since the crack front is not defined by a line, but there is band of damaged material undergoing stiffness degradation until complete decohesion. Therefore, the concept of growth driving direction (GDD) [3] is proposed and used instead. The GDD is defined as the normal to a damage isoline. This definition provides the exact same result as the normal to the crack front in the limiting case where the length of the fracture process zone goes to zero, but it is not restricted to brittle materials.

Because of the, so far, lack of efficient methodologies to identify the propagation direction, the mode-decomposition of the energy release rate into modes I, II and III in arbitrarily shaped delamination fronts modeled using a CZM approach has not been previously investigated. The J-integral approach is a suitable method for computing this, because its domain-independence allows shrinking the integration domain to the cohesive interface, and reducing it to a line integral. In this work, a new formulation for the evaluation of the mode-decomposed J-integral in delamination fronts involving large fracture process zones is presented [4]. The growth driving direction is used to render the integration paths across the fracture process zone and to decompose it into modes. In the general case, this results in curved integration paths.The formulation is validated against VCCT and linear elastic fracture mechanics analytical solutions. Moreover, its generality is demonstrated by application to a three-dimensional composite structure developing a large, curved and non-planar facture process zone.

REFERENCES

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