

Predicting nucleation and propagation of fibre-matrix debonds under transverse tension by minimising the total energy subject to a strength condition

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Abstract

The Coupled Criterion (CC) of Finite Fracture Mechanics (FFM) [1] is employed to predict the initiation and propagation of fibre-matrix debonds in a unidirectional lamina under transverse tension. According to the CC-FFM, the stress and incremental energy criteria are the necessary and sufficient conditions for the onset or propagation of a crack by a finite extension. First, a novel formulation of the CC-FFM based on the Principle of Minimum Total Energy subjected to a Strength Condition (PMTE-SC) [2-3] is presented. PMTE-SC is better suited to generic computational implementation of a load-stepping technique than the classical formulation of CC-FFM. A computational implementation of PMTE-SC can solve fracture problems involving the propagation of multiple cracks, as well as their initiation at stress concentrations and singularities. It can also address the interaction of cracks with interfaces and propagation of interface cracks. To model interface cracks using a damage variable, continuous distributions of linear elastic springs (Winkler model) are considered on interfaces. This enables the total energy (given by the sum of the potential and dissipated energy) to be defined in terms of the displacement and damage variable fields in each load step. The key advantage of this approach is that the total energy is a separately convex functional in terms of the displacement and damage variable fields. This makes it possible to

apply an Alternate Minimisation Algorithm (AMA) which is both efficient and robust optimisation technique to minimise the total energy subject to constraints given by a strength criterion. The Finite Element code Abaqus and Python scripts are used to implement this procedure based on PMTE-SC. The user subroutine defines the interaction along an interface by a Winkler spring distribution. Several examples of modeling fibre-matrix debond nucleation and propagation in a unidirectional lamina under transverse tension are presented. The bimaterial systems considered include one and several glass fibres embedded in an epoxy matrix. Thus, this methodology opens up new possibilities for studying debond onset and propagation in fibre reinforced composites. [1] D. Leguillon, Strength or toughness? A criterion for crack onset at a notch. *European Journal of Mechanics A/Solids* (2002) 21, 61–72. [2] V. Mantič, Prediction of initiation and growth of cracks in composites. Coupled stress and energy criterion of the finite fracture mechanics (Keynote Lecture), in: *Proc., 16th European Conference on Composite Materials (ECCM16)*, F. París (Ed.), 2014. [3] M. Muñoz-Reja, V. Mantič, L. Távora, Comparative analytical study of the coupled criterion and the principle of minimum total energy with stress condition applied to linear elastic interfaces, *Theoretical and Applied Fracture Mechanics*, 119 (2022) 103274.

Keywords:

fibre-matrix debond transverse load unidirectional lamina debond nucleation multi-site damage Finite Fracture Mechanics FEM