MULTIPLE DELAMINATIONS PREDICTION ON ILTS SPECIMENS BY AN ABAQUS IMPLEMENTATION OF THE COUPLED CRITERION OF FFM AND LEBIM

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Abstract

Inter-Laminar Tensile Strength (ILTS) test uses L-shaped composite coupons with laminas having different orientations. To model multiple delaminations that occur in ILTS specimens a quite general formulation of the Coupled Criterion of Finite Fracture Mechanics (CCFFM) with the Linear Elastic-perfectly Brittle Interface Model (LEBIM) is applied.

1. Introduction

Experimental results have shown that, in many cases, ILTS coupons fail under interlaminar stresses lower than their allowable values (determined with unidirectional coupons). Preliminary analytical studies have qualitatively attributed this inconsistency to the failure mechanism called induced unfolding. According to this mechanism, failure starts with an intralaminar crack which, under a sufficiently large interlaminar stress (although under its allowable value), propagates instantaneously as a delamination. In the present investigation, this mechanism is modelled using a quite general formulation of the CCFFM + LEBIM based on the Principle of Minimum Total Energy subjected to a Stress Condition (PMTE-SC). This formulation is implemented in a computational procedure in Python using the commercial FEM code Abaqus®, which solves the total energy minimization problems separately in terms of displacements and an interface-damage variable in each load step.

2. Results

The PMTE-SC, employing a load-stepping procedure, minimizes the Total Energy functional, the sum of the Potential and Dissipated Energies, in the feasible region of all possible new crack configurations given by the stress criterion, in each time step. A great advantage of PMTE-SC is that the Total Energy is separately convex in displacements and damage variable, this feature allows solving convex optimization problems separately in terms of displacements and damage variable in each load step, which makes this procedure very robust and efficient especially if a suitable staggered scheme of minimization is applied. In the literature similar staggered schemes are also referred to as Alternating Minimization Algorithms (AMA).

In the ILTS test, a four-point bending test tooling applies a purely bending load to the curved part of the specimen. For this purpose, the test includes four freely rotating rollers in contact with the specimen. The chosen stacking sequence is $[45,-45,90_2,0,45,-45,0]_S$ and it is named as QI16. This laminate has been chosen to minimize the ratio between the failure load due to induced unfolding and the failure load due to traditional unfolding. It is a quasi-isotropic, symmetric, and balanced laminate. The induced unfolding mechanism appears in the 90° oriented laminae in the innermost part of the specimen. This is due to the fact that the matrix of this sheet supports tensile stresses, and the strength of the matrix subjected to tensile stresses, Y_t, is significantly smaller than the rest of the strengths. This facilitates the appearance of microcracks, which after coalescence produce intralaminar failure. This failure propagates in an instable manner in the form of delaminations. To capture the progressive evolution of the damage, the test should allow the simultaneous reduction of the load and the displacement, thus producing an unstable appearance of the damage, this type of instability is known as snapback. In experimental tests, almost instantaneous delamination occurs at the remaining interfaces, so it is not trivial to determine the point or points at which failure initiates. In classical numerical simulations, this behavior manifests itself in the form of convergence problems due to sources of model nonlinearities, thus the use of a robust numerical tool is needed.

Figure 1 shows the damage variable along the interface in the analyzed 2D FEA model. By not allowing intralaminar failure, delaminations occur because the maximum interlaminar normal stress is reached. This stress has a quadratic distribution, and reaches its maximum in the central zone, so that the central interfaces have approximately the same probability to fail. This is the reason why delamination occurs at several interfaces almost simultaneously.

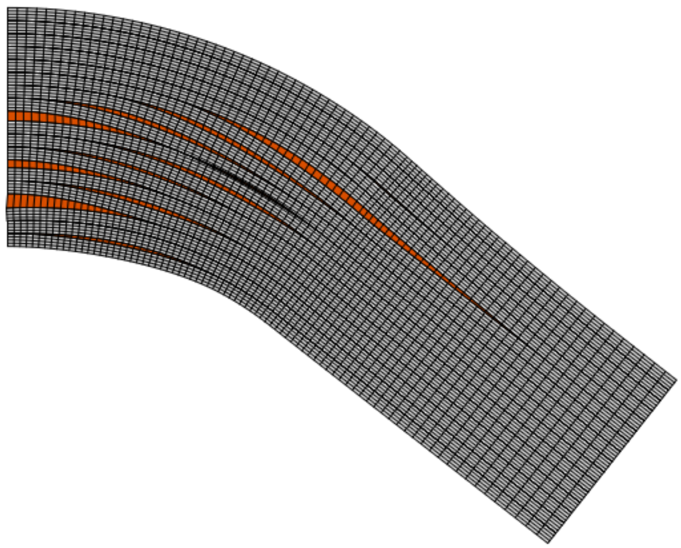

Fig.1 – Damaged ILTS half-specimen.

3. Conclusions

The PMTE-SC has shown to be an adequate tool to predict multiple delaminations on ILTS specimens. It has been found that the most critical case for the laminate under consideration is induced unfolding. There are two methods to identify which failure mechanism has initiated the process. The first is by observing where the delaminations occur; in induced unfolding they appear in the inner zone while in traditional unfolding it occurs in the central zone. The second is by looking at the failure load, since in the induced unfolding case, the failure load is considerably lower than the one obtained in traditional unfolding.

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