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MESOLEVEL REPRESENTATION OF SPLITTING IN LAMINATES

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ABSTRACT

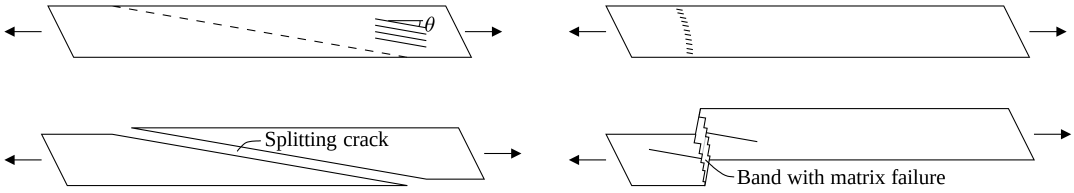
Failure of laminates is often dealt with on the mesolevel, where a laminate is considered to be consisting of homogeneous plies, each with orthotropic properties that depend on the fiber orientation. Although initiation and progression of failure inside a ply are typically micromechanical events, related to the particular microstructure and irregularities therein, the mesolevel approach is adopted because explicit modeling of the whole microstructure is computationally unaffordable. For this purpose, assumptions are needed on how micromechanical failure can be represented on the mesolevel. One of the choices that has to be made is that between a discrete representation, with interface elements or the extended finite element method (XFEM), and a continuum representation, with continuum damage or softening plasticity models.

Analysis of progressive failure in laminates should include a representation for each of the different processes that are expected to occur, for instance delamination, matrix cracking, fiber/matrix debonding, fiber breaking and fiber kinking. For delamination, use of cohesive zone models in a discrete representation is common. For failure inside the plies, however, the continuum representation is attractive because intact plies are modeled as a continuum, where failure can be introduced relatively straightforward via a nonlinear relation between stress and strain.

One of the processes that may occur inside individual plies, well before final failure of the laminate, is splitting: the process in which matrix cracks, which initiate at a stress concentration, propagate parallel to the fiber direction in a single ply. Splitting cracks have been observed in experiments as significant subcritical damage and for some configurations also as part of the final failure mechanism [1,2].

Recently, several continuum damage models have been proposed in the context of composite materials (see e.g. [3–5]). In this paper, the performance of such a model is compared with that of a softening plasticity model, for cases in which splitting is one of the processes of importance. Special attention is paid to the mesh dependency issue. To resolve this, both material models are enhanced with artificial viscosity, which leads to the existence of a localization zone with a finite mesh-objective width.

It is shown that neither of the continuum descriptions is able to capture the split in a 10° off-axis tensile test properly. In this simple test, in which splitting is the only significant failure mechanism [6], the predicted failure pattern is unrealistic with both continuum damage and softening plasticity models.



(a) Experimental observation (b) Simulation with continuum model

Figure 1: Discrepancy between mechanism observed in experiments and mechanism obtained from computational analysis with a continuum failure model.

Notably, the explicit distinction between matrix failure and fiber failure in the continuum damage model does not prevent the matrix failure from localizing in a band which is crossed by fibers (see Figure 1).

Furthermore, it is illustrated how this pathology leads to unrealistic failure patterns in more complicated analyses. In the example of a notched plate with a $[0/90]_s$ layup, a split is supposed to appear in the 0°-ply, accompanied with delamination. It is shown that it is possible to capture this split with the continuum models, but that it is impossible to do the complete analysis including final failure of the laminate with a single set of material parameters and obtain realistic failure patterns.

An XFEM formulation is proposed to capture splitting. With this formulation it is possible to represent cracks in a discrete fashion, such that the location of the cracks is not specified in advance while the direction is predefined. This way, the micromechanical feature that a split propagates parallel to the fiber direction, which is lost in the homogenization assumption inherent in continuum models, is transferred to the mesolevel. Capturing the crack in a 10° off-axis tensile test becomes a trivial task, which will be exemplified.

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