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TOWARD THE DAMAGE COMPUTATION ON THE MICRO-SCALE OF LAMINATED COMPOSITES

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Summary. *Damage and final fracture of laminated composite structures are described thanks to a very sound physical micromodel which is semi-discrete and probabilistic. Unfortunately, such a micromodel leads to prohibitive computations with classical codes. An alternative computational strategy capable of solving such a problem is proposed. It is a multiscale strategy which includes homogeneization in space and in time without introducing any periodic conditions. First simulation examples are shown and compared to experiments.*

1 INTRODUCTION

The last quarter-century has witnessed considerable research efforts in the mechanics of composites aimed to understand their behavior and to model or calculate them - the ultimate goal being the design of the materials/structures/manufacturing processes. Even in the case of laminated composites, which are the most studied and, therefore, the most understood, the prediction of the evolution of damage up to and including final fracture remains a major challenge. Today, the use of laminated composites in the aerospace industry always involves characterization procedures consisting of huge numbers of tests, which shows the low level of confidence in models. Significant improvements in this situation could be achieved if one could create a real synergy among the approaches on different scales which, today, are followed quite independently of one another in the case of laminated composites. One could jokingly say that there is, on the one hand, the micromechanics of laminates where one counts cracks ([1],[2],[3],[4]) and, on the other, the meso- or macromechanics of laminates in which one measures stiffness ([5],[6]) - with only few links between the two. How to bridge the micro- and mesomechanics aspects was a first and important issue discussed in a previous work ([7]). The question being adressed here is the impact of such a bridge on the models themselves, especially the micromodels, the objective being to calculate the intensities of the damage mechanisms at any point of laminated structures subjected to complex loading and at any time until final fracture resulting from strain and damage localization.

2 Microphenomenology and the damage micromodel

It is assumed that any complex state of degradation of a laminated composite is due to the accumulation and subsequent localization of a family of elementary mechanisms. These mechanisms (Figure 1) can be classified into two groups according to their apparent morphology on the ply's scale.
The first group consists of discrete phenomena, in which cracked surfaces can be clearly identified on the ply's scale and which correspond to the classical mechanisms introduced in micromechanics. We are considering "transverse microcracking" for which microcracks spread throughout the thickness of the plies and "local delamination" which appears at the interfaces between plies (see [4] for reviews). The second group consists in "continuous" mechanisms, which on the ply's scale lead to a seemingly homogeneous, but damaged, material. These two mechanisms which are not usually introduced in micromechanics, are associated with quasi-homogeneous fibre-matrix debonding within the layer ("diffuse damage") and with microvoids within the interlaminar interface ("diffuse delamination").

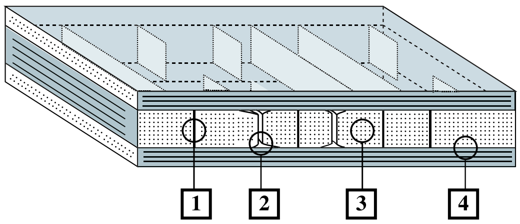

Figure 1: The mechanisms of degradation on the microscale. 1: transverse microcracking, 2: local delamination, 3: diffuse damage, 4: diffuse delamination

On the microscale, the structure is described as an assembly of layers, made of the fiber-matrix material, and interfaces, which can be cracks. The proposed computational micromodel for laminates is hybrid ([8]). The fiber-matrix material is described through the classical continuum mechanics framework and follows the classical damage mesomodel for laminates : diffuse damage ([5],[6]) and, if necessary, (visco) plasticity. The surfaces of the cracks are described using a discrete model by introducing "minimum cracked surfaces". The minimum cracked surfaces related to transverse microcracking are square surfaces, parallel to the fiber, whose dimension is the thickness of the ply and is choosen from energetical considerations. Discrete mechanisms are studied in the framework of finite fracture machanics. Discrete damage forces and critical damage forces are thus introduced and enables to take into account difference between initiation and propagation. The critical values of the energy release rate are stochastic fields.

2.1 The multiscale computational strategy

The possible cracks are defined *a priori* in the computations in progress and are connected to the mesh. In the classical finite element method, a reasonable mesh would lead to problems with approximately 10^{10} degrees of freedom for a low velocity impact problem on a laminated composite. We use a parallel and iterative approach based on a "multi-scale homogeneization in time and space" proposed in ([9],[10]). The description of the solution using multiple scales reduces the number of degrees of freedom drastically. Two scales lead to approximately 10^8 unknowns problems to solve. In order to get reasonable calculations, it is necessary to introduce an additional scale (a macro scale), which would lead to 10^6 macro unknowns problem.

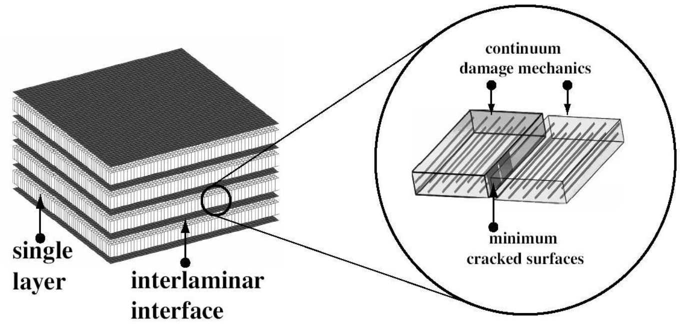

Figure 2: The computational damage micromodel : minimum cracking surfaces

3 Illustration : static axial loading on cross-ply laminates

We carried out basic simulations on cross-ply laminates with material properties representative of carbon-epoxy composites, sujected initially to thermal loading due to the process then to pure mechanical loading in tension. The interfaces between elementary cells may fail to reproduce transverse microcracking. When an elementary surface is cracked, unilateral contact conditions with friction apply are applied.

Figures 3 and 4 show that the model seems capable of reproducing the main basic features of classical experimental results. Simulations were also carried out on laminates with different stacking sequences.

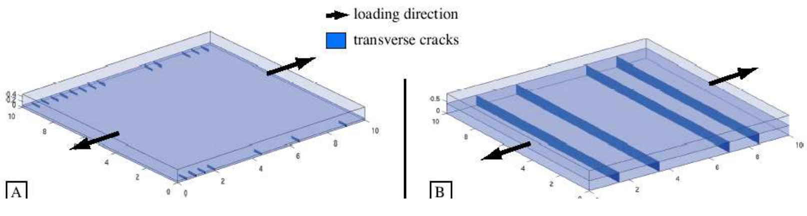

Figure 3: Comparison of the cracking patterns (A) in thin laminates ($[0_6/90]_{\bar{s}}$) and (B) in thick laminates ($[0_3/90_3]_s$)

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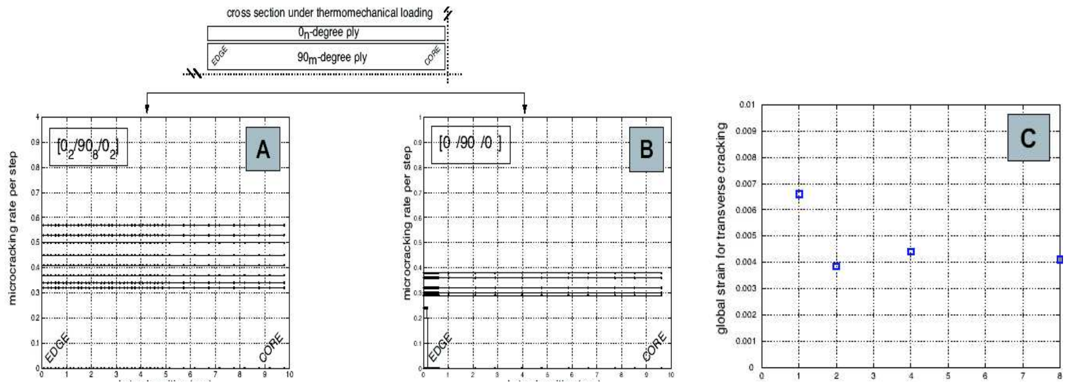

Figure 4: (A/B) : microcracking rates from edge to core in the central ply of cross-ply composites at each step of the calculation. C: strain at the beginning of microcracking vs. the ply's thickness

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