MATRIX MICROCRAKING AND SPLITS MODELING IN LAMINATED COMPOSITES

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Abstract
This paper considers transverse cracking damage with particular emphasis on splitting phenomenon. The context is related to industrial composite structures submitted to extreme loads, and whose behavior is highly non linear. In this work, a strategy to detect splits by an ad hoc criterion is proposed and a full framework is presented in order to represent splits accurately. The implementation of the strategy has been done in SAMCEF commercial software.

1. Introduction

The last quarter-century has witnessed considerable research efforts in the mechanics of composites in order to understand and predict the behavior of these materials, the ultimate goal being the design of the materials/structures/manufacturing processes. Even in the case of laminated composites, the prediction of the evolution of damage up to and including final fracture remains a major challenge which is at the heart of today's virtual structural testing revolution engaged in by the aeronautical industry. Virtual structural testing consists, whenever possible, in replacing the numerous experimental tests used today by virtual tests. An answer to the virtual structural testing challenge is what is called the damage mesomodel for laminated composites, developed at LMT-Cachan since the 1980's. The main asumption is that the behavior of any laminate under any loading up to final fracture can be described using two elementary entities: the ply and the interface. It is derived from today's understanding of the mechanisms of damage and their evolutionon the micro, meso and macroscales. The damage mesomodel we proposed and which is used in a number of industrial codes could be viewed as the homogenized version of a micromechanics model. It includes a model of the interaction between delamination and ply microcracking which depends on some micromechanical material constants. Today several similar mesoscopic approaches are being developed. However, the prediction from such a model could me much too conservative in some cases e.g composite structures involving extensive splitting. Here, the mesomodel has been found to present a shortcoming; due to numerical constants, the calculated splits, i.e. the completely damaged zones due to matrix microcracking, are too thick.

The paper deals with this challenge of modeling accurately the transverse microcracking and split in the ply. Already several approaches have been proposed. A first approach is the high-fidelity micromechanic model where every single discontinuity in the plies and in the interfaces is described and therefore, one has to solve numerically a very large scale problem involving thousands of cracks. Even with a high performance computational tools, such a micromechanic model leads to prohibitive computational effortsand, thus, is far from meeting the virtual structural testing requirements. However, fundamentally, a split appears to be as a particular microcrack relatively isolated and mainly due to shear a part from

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purely microscopic and mesoscopic approaches, intermediate approaches have recently proposed in the literature. Classical cohesives interfaces are a priori introduced for transverse microcracking and combined with delamination interfaces. Two ways can be distinguished. The first uses a priori experimental information about the cracking pattern (e.g. the position of the splits) and then a predictive approach. The second considers a set of equally space potential cohesive interfaces in the different plies. To avoid prohibitive computations, the distance between two cohesive interfaces cannot be too small and then is not necessary compatible with the micromechanics physics. This question has lead to interrogation related to the capability of “continuum damage mechanics” to reproduce splits. Some authors conclude with absolute necessity to use discrete models.

Our understanding is quite different. The difficulty to get “thin” splits with our mesomodel is only due to numerical problems associated to localisation phenomena involving very small time and space discretization. The mesomodel where microcracking is described by microcracking density is correct; a split appears as a localization phenomenon. The paper proposes a new approach which allows to simulate microcracking densities and splits. The main idea is to remark that until microcrack initiation, continue damage models and their numerical implementation do not involve any difficulty; localisation limiters are not active. So, one detects first the split initiation and then one replaces it by a cohesive interface orthogonal to the ply thickness and parallel to the fibers. Apart one has a microcracking density all over the different plies. After given the fundamentals of proposed approach, an illustration is developed in order to compare the classical mesomodel with the proposed approach. Comparison with experiments is also shown.

2. The mesomodelization

To predict the failure of composite materials still remains an important scientific challenge in today’s research. Composite materials are by nature heterogeneous and multiscale what makes their modelization very complex. The existing proposed models have to be discriminated according to the characteristic scale of the V.E.R. Micromodels are built on a “fiber section” ($\approx 10\mu m$) scale description, macromodels on the “the characteristic structure length” ($\approx 10cm$). Mesomodel is based on an intermediate characteristical length: the layer thickness ($\approx 100\mu m$). The main assumption of the model is that failure of laminated composite structure can be comprehended using only two mesoconstituents: the ply and the interface. These mesoconstituents are equiped with damage indicators derived from continuum damage mechanics in order to describe the whole scenario of the material ruin. In a general way, mesomodel takes advantage of the good physical micromechanical description of the material and the cheap computationnal costs of macromodels. The Cachan mesomodel has been proposed at the end of the 1980’s [1] and to deal with the multiscale aspects of the material, a micro-meso brige has been set up between micromechanics damage variables and meso damage variables especially for transverse cracking description [2, 3]. As a result, the Cachan mesomodel is in agreement with physical micro-mechanics observations. One uniqueness of this mesomodel is the ability to describe transverse cracking and delamination interactions and the scale effects [4].

3. Split detection and computation

Composite materials suffer from a large complexity of their behavior. Computational mechanics tries to simulate and reproduces the variety of composite material patterns but several key aspects remains badly represented. The issue that is discussed here is about splitting phenomenon. Splits are sharp cracks that come out in fiber direction and which can be easily observed testing a hole plate which layers are unidirectional. These thin cracks make results obtained by simulation inacurate. The crack entails a redistribution of the stress that move deeply the first calculation.

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To model and simulate splits is not an easy task. A first strategy is to model every single crack in the plies and in the interfaces, consequently one has to solve numerically a very large scale problem involving thousands of cracks. This approach is described in [5]. Even using parallel computation strategy, such a micromechanic model leads to prohibitive computational efforts and, thus, is far from meeting the virtual structural testing requirements. However, fundamentally, a split appears to be as a particular microcrack relatively isolated and mainly due to shear [6]. From purely microscopic and mesoscopic approaches, intermediate approaches have recently been proposed in the litterature. Classical cohesive interfaces are a priori introduced for transverse microcracking and combined with delamination interfaces. Two ways can be distinguished. The first one uses a priori experimental information about the cracking pattern (e.g. the position of the splits) and then is not a predictive approach [7]. The second one considers a set of equally space potential cohesive interfaces in the different plies. To avoid prohibitive computations, the distance between two cohesive interfaces cannot be too small and then is not necessarily compatible with the micromechanics [8, 9]. Anyway these approaches do not give the continue part of the microcracking density.

The former version of damage mesomodel assumes that transverse cracking is periodic. However, in splitting case one can observe a localization of transverse cracking in only one macrocrack. In this particular case, the former version of the model requires to pay a very refined mesh to catch the singularity accurately. If not, using a coarse mesh, the prediction be much too conservative and the predicted damaged zones due to matrix microcracking, are too thick. This solution increases computation costs and is not the successful industrial strategy we choose. The way we propose to tackle the problem is to describe the crack in a discrete way by injecting cohesive elements where the split occurs.

The difficulty to get thin splits with the mesomodel is only due to numerical problems associated to localisation phenomena involving very small time and space discretization. The mesomodel where microcracking is described by microcracking density is correct; a split appears as a localization phenomenon. The new approach introduced in [10] is able to simulate microcracking densities and splits. The main idea is to remark that until split initiation, continuum damage models and their numerical implementation do not involve any difficulty; localisation limiters are not active. So, one detects first the split initiation and then one replaces it by a cohesive interface, orthogonal to the ply and parallel to the fibers (its height is the thickness of the ply).

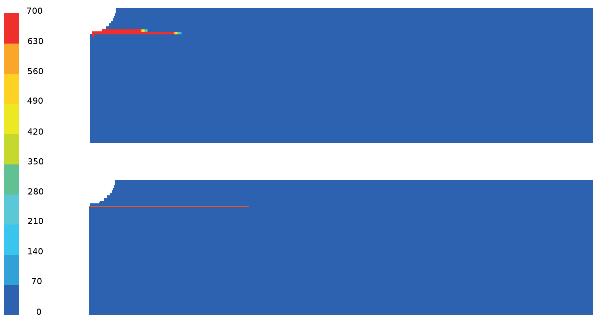

Figure 1. Microcracking computation with mesomodel former (at the top) and new approach (below)

Split detection criterion. — Let us compute first the part of the dimensionless microcracking density shear due to shear; the criterion is:

$$M \in \Omega_{0.2} = \arg\max \left(\frac{\rho_{shear}}{\rho} (M) \quad | \, M \in \Omega_{0.2} \; ; \; 0.75 \right)$$

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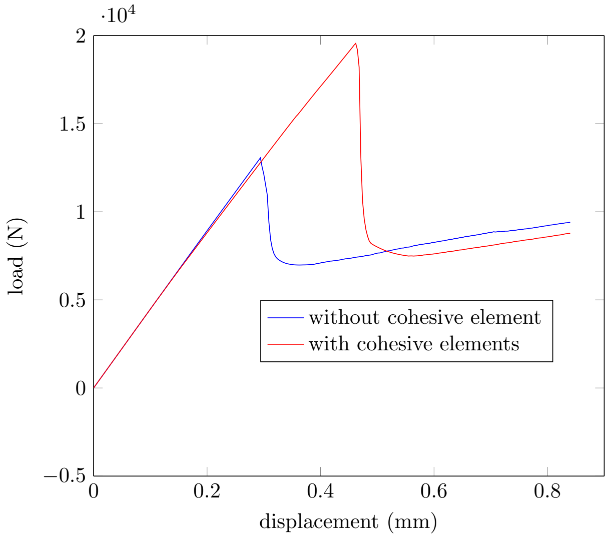

Figure 2. Load Displacement curve computed with mesomodel, former (at the top) and new approach (below).

where $\Omega_{0.2} = \{M \in \Omega \mid \rho(M) \geq 0.2\}$

Split propagation. — One introduces a cohesive interface governed by continuum damage mechanics where the split has been detected. The support is orthogonal to the ply and parallel to the fiber. Its height is the plane thickness, and one supposes that its damage variables are constant over the thickness of the ply.

Its critical energy release rates are those of the microcracking phenomena. Still for the $[0_2/90_2]_S$ tension test. One illustrate after the great importance of taking into consideration splits, considering the load displacement curve for both strategy (Fig 1, Fig 2).

4. Conclusions

A new approach to tackle with transverse cracking localisation has been proposed and the feasibility of the method has been proved. Due to industrial requirements, the detection/computation strategy for splits has been fully implemented in SAMCEF commercial code. The goal is to be able to compute for a large range of parameters mechanical response in order to form virtual charts that are going to replace experimental curves used by engineers to design composite structures. The deformation energy that is injected in the problem is limited and so the problem that is solved is nearer to the initial composite modelization. Moreover cohesive elements are not introduced at the beginning but on-the-fly during the calculation using an ad hoc criterion based on microcracking. Finally a comparison between results and experimental tests was made.

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