A BRIDGE BETWEEN THE MICRO- AND MESOMECHANICS OF LAMINATES: FANTASY OR REALITY?

Pierre Ladevèze
LMT-Cachan, ENS Cachan/CNRS/Université Paris 6, 94235 Cachan Cédex, France

Summary The main questions discussed here are how to bridge the micro- and mesomechanics of laminates and how this affects the understanding and prediction of localization and final fracture.

MOTIVATIONS: THE SCIENTIFIC AND INDUSTRIAL CHALLENGES

The last quarter-century has witnessed considerable research efforts in the mechanics of composites in order 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 stratified composites (which are the most studied and, therefore, the best understood), the prediction of damage evolution up to and including final fracture remains a major challenge in the modern mechanics of composite materials and structures. Today, the use of stratified composites in the aerospace industry always involves characterization procedures consisting of huge numbers of tests, which shows the low level of confidence in models. A significant improvement in this situation, i.e. a drastic reduction in the number of industrial tests, 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 stratified composites. One could jokingly say that there is, on the one hand, the micromechanics of laminates where one counts cracks and, on the other, the meso- or macromechanics of laminates where one measures stiffnesses – with only few links between the two. How to bridge the micro- and mesomechanics aspects and how this affects the understanding and prediction of localization and final fracture are the two main questions discussed here.

THE DAMAGE MICROMECHANICS OF LAMINATES

Up to now, there have been numerous theoretical and experimental works on the micromechanics of laminates [see (1) – (4)]; the micromechanics approach provides a relatively good understanding of damage mechanisms, such as matrix microcracking. However, these micromechanics models are lacking in some respects: in particular, they are far from being complete for the prediction of localization and final fracture.

THE DAMAGE MESOMECHANICS OF LAMINATES

Alternative, pragmatic computational approaches have also been developed. In our lab, we focus on what we call a « damage mesomodel for laminates » [see (5) – (6)]. In this approach, one assumes that the behavior of any laminated composite for any loading and any stacking sequence can be modeled using two elementary constituents which are continuous media: the ply and the interface. Another important point is that the state of damage is assumed to remain constant throughout the thickness of the single layer (of course, it can vary from one layer of the laminate to the next.)

TOWARD A BRIDGE BETWEEN MICRO- AND MESOMECHANICS

The central question we aim to discuss here is: how can one bridge the micro- and mesomechanics of damage? The belief that such a complete bridge could exist is not shared by all the people working in micromechanics. A first attempt at building such a bridge was made in (7) (8) for plane macrostresses. The mesomodel was found to be fully compatible with the microdamage mechanisms. The micro-meso relations introduce quantities or relations which we call “approximately ply-material”, which are intrinsically related to the cracked ply’s characteristics and, therefore, independent of the characteristics of the other plies. Recently, additional work has extended this approach to out-of-plane stresses (9). This more complex situation involves non-local mesomodels, as there are interactions between the interface’s damage and the microcracking mechanisms of the adjacent plies. The method of investigation is now entering what is called a “virtual testing” stage, in which numerous numerical experiments using the micromodel and involving various possible stacking sequences, thicknesses,… are performed. One can show that the micromechanisms within the plies and interfaces can be homogenized; relations between the micro- and mesoquantities can be obtained through the resolution of several basic problems.

THE MULTISCALE APPROACH AND SOME APPLICATIONS

The second question being discussed here is the impact of such a bridge on the micro- and mesomodels themselves, the objective being to calculate the intensities of the damage mechanisms at any point of a laminated structure subjected to complex loading and at any time until final fracture resulting from strain and damage localization. These improved models require a multiscale approach. A first example is an improved damage mesomodel for laminates allowing the

calculation of the intensities of the damage micromechanisms. A second example is a "computational damage micromodel" which is rather simple, yet semi-discrete and probabilistic; unfortunately, this model leads to prohibitive calculation costs if one uses current industrial codes. The use of a multiscale computational strategy is absolutely essential. Several examples are worked out in order to show the capabilities and the limitations of the different models.

References

[1] Laws N., Dvorak G.J.:Progressive Transverse Cracking In Composite Laminates *J. Comp. Mat.* **22**, 900-916, 1988.

[2] Hashin Z.: Analysis Of Cracked Laminates : A Variational Approach Mech. Mat., **4**, 121-126, 1985.

[3] Nairn J., Hu S.H.: Matrix Microcracking Damage Mechanics of Composites Materials, Taljera R. (Ed), Elsevier, 187-243, 1994.

[4] Berthelot J.M.: Transverse Cracking And Delamination In Cross-Ply Glass Fiber And Carbon-Fiber Reinforced Plastic Laminates : Static And Fatigue Loading Appl. Mech. Rev., **56**, **1**, 1-37, 2003.

[5] Ladeveze P.: On Damage Mechanics Of Composites", C.Bathias And D. Menkès, Comptes-Rendus Des Jnc5, Pluralis 667-683 (In French) 1986.

[6] Ladeveze P., Allix O., Deü J.F., Leveque D.: A Mesomodel For Localization And Damage Computation In Laminates Comput. Methods Appl. Mech. Engrg. **183**, 105-122, 2000.

[7] Ladeveze P., Lubineau G.: On A Damage Mesomodel For Laminates : Micro-Meso Relations, Possibilities And Limits, Comp. Sci. Tech., **61**, 2149-2158, 2000.

[8] Ladeveze P., Lubineau G.: An Enhanced Mesomodel For Laminates Based On Micromechanics Comp. Sci. Tech., **62**, 533-541, 2002.

[9] Ladeveze P., Lubineau G., Marsal D.: Toward A Bridge Between Micro And Mesomechanics Of Delamination Comp. Sci. Tech., (To Appear) 2004