COMPUTATIONAL MICRO-MESO MODELING FOR LAMINATES UNDER THERMOMECHANICAL FATIGUE AND AN OXIDIZING ATMOSPHERE

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Summary One computational approach for studying damage in laminated composites is the damage mesomodel for laminates, which has been developed for more than fifteen years, particularly at LMT-Cachan. Recently, we introduced micro-meso relations which prove that this mesomodel is compatible with classical micromechanical analysis and, therefore, can be viewed as a homogenization of classical theories on the microscale. Consequently, basic material quantities on the microscale can be easily interpreted on the mesoscale. Here, we propose to use these micro-meso relations as a tool for studying the degradation of laminates under fatigue in an oxidizing atmosphere. The reason why we are interested in this specific topic is that carbon-epoxy laminated composites are candidate materials for the construction of the future European civil supersonic aircraft. Our approach is rather simple: first, the influence of fatigue or oxidation on basic material characteristics is studied on the microscale; then, the equivalent damage evolution law on the mesoscale is obtained thanks to the micro-meso relations.

THE COMPUTATIONAL MICRO-MESO APPROACH FOR LAMINATES

The micro-meso relations for laminates

One of the computational approaches applicable to laminated composites is based on what we call a damage mesomodel for laminates, whose characteristic length is the thickness of the elementary ply ([1]). In such an approach, one assumes that the behavior of any laminated composite can be constructed using two elementary constituents which are continuous media: the ply and the interface ([3],[4]). The ply takes into account diffuse damage (quasi-homogeneous debonding of fiber/matrix interfaces), transverse microcracking, and local delamination (debonding of the interlaminar interface near the tip of each transverse microcrack). The interface is a surface entity which provides for the transfer of strains and stresses between plies.

Recent works ([7],[8]) using “virtual material testing" proved that the damage mesomodel can be viewed as a homogenized version of classical microdegradation schemes ([5], [2], . . .). The guiding principle is that for each mesoconstituent the relations between micro quantities (e.g. microcracking rates, energy release rates, . . .) and meso quantities (damage indicators and damage forces) are approximately independent of the stacking sequence in which the mesoconstituent is present. Consequently, there exist intrinsic operators (i.e. operators which depend only on the mesoconstituent being considered) which link the solutions on the two scales for any state of degradation.

Now it should be possible to design improved computational tools for damage analysis in two ways. First, thanks to that link, it is possible to build a damage mesomodel for laminates which relies extensively on micromechanics concepts. Quantities which have a strong meaning on the microscale (such as the critical energy release rate) can also be interpreted in the meso law of degradation. Consequently, this micro-meso link may be a way to introduce modifications of the properties due to mechanisms on the very fine scale into the calculation of the structure. Second, micro-meso relations can also be used as tools for interpreting the results of meso calculations in terms of the levels of microdegradation schemes. This provides a better physical understanding of the calculations.

Illustration under quasi-static and fatigue thermomechanical loading

Here this approach is first illustrated in the case of quasi-static and fatigue loading.

For quasi-static loading, we show that the basic mechanisms introduced on the microscale lead to consistent behavior on the mesoscale. First, the model is capable of predicting matrix microcracking for cross-ply laminates under tension. Second, thanks to the introduction of diffuse damage mechanisms on the microscale, the model is also capable of predicting the stiffness reduction under high shear loading, even though no microcracking occurs ([6]).

Concerning cyclic loading, our main assumption is that the diffuse damage mechanism alone is related to fatigue. We also assume that an increasing level of homogeneous diffuse damage leads to a progressive reduction of the ply’s toughness with respect to transverse microcracking ([9]). Consequently, if this toughness reduction becomes significant, transverse microcracking, for which the evolution law under quasi-static loading remains valid, develops. Contrary to classical micromechanical analysis, this approach still uses for fatigue microcracking the important concept of energy release rate, which leads to a consistent description of microcracking under quasi-static and cyclic loading. Thus, through the introduction of these micromechanical concepts, the micro-meso relations lead to an improved damage mesomodel for laminates.

INTRODUCTION OF THE EFFECT OF OXIDATION

Since this mesomodel can be interpreted as a homogenization of classical micromechanical models, basic quantities which have a strong material meaning on the microscale can now be interpreted directly on the mesoscale. Therefore, it is relatively simple to construct a computational tool on the mesoscale which takes into account oxidation. First, the effects of oxidation can be completely quantified on the microscale as modifications of the basic properties of the material. Then, these modified microquantities are used to get the equivalent damage law on the mesoscale, using the micro-meso relations. It appears that this approach could be used for any type of physical or chemical mechanism which modifies the material properties in an approximately homogeneous way throughout the thickness of the elementary ply (as long as it remains consistent with the basic hypothesis of the damage mesomodel).

In a very general way, transverse microcracking occurs when the energy release rate of the ply, depending on the loading (i.e. intralaminar stresses), on the level of damage (i.e., for example, the microcracking rate ρ) and on several basic properties of the ply (elastic modulus, thickness, etc.), reaches a certain critical energy release rate, which is a material quantity.

In the particular case of thermal oxidation, two major modifications appear on the microscale. First, the more oxidized the matrix, the more brittle it is. Thus, the critical energy release rate for microcracking must be considered to decrease with the amount of oxidation. Second, the increasing density of the matrix with oxidation ([10]) leads to shrinkage of the matrix between fibers and, therefore, to oxidation-induced intralaminar stresses.

Several simulations were performed on the mesoscale taking into account these considerations on the microscale. Comparisons are made with experimental observations on carbon-epoxy laminates under thermomechanical fatigue loading and an oxidizing atmosphere. We show that our approach is suitable for the description of the major aspects of damage behavior.

CONCLUSIONS

We presented an initial attempt to include on the mesoscale modifications of the material due to physical and chemical mechanisms on the very fine scale. This approach is based on the use of micro-meso relations developed at LMT-Cachan as a tool for transmitting information from the fine scale (the microscale) to the coarse scale (the mesoscale).

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