Global-local finite element strategies for the simulation of damage in large composite structures under dynamic loading conditions.

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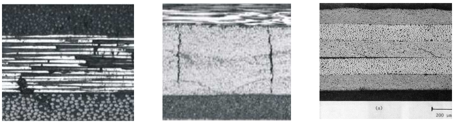
I. INTRODUCTION

Composite materials consist of two or more separate phases. These materials are ideal for structural applications where high strength-to-weight and stiffness-to-weight ratios are required, for example wind turbines, aircraft, spacecraft or automotive applications. Fibre Reinforced Plastics (FRP) are nowadays largely used in these applications, where the matrix (polymer) is reinforced in a defined direction with fibres (e.g. carbon). The plies of a fibre-reinforced plastic composite, can be stacked under different fibre angles to form a so called ‘laminate’ with desired stiffness and strength in different directions. Since the material can be tailored to meet special demands, Laminated Composite Structures (LCS) can be lighter and made with superior characteristics when compared to traditional single-phase materials.

However, as it is the case for single-phase materials, laminated composite materials are susceptible to damage. Damage may occur in the form of microcracks and voids, and usually leads to macroscopic loss of stiffness and strength. The use of composite materials introduces new challenges in the design and analysis process along with the emergence of new damage mechanisms. The damage mechanisms can be divided into intralaminar and interlaminar damage, and may lead to catastrophic structural collapse.

As shown in Figure 1 intralaminar damage mechanisms correspond to fibre fracture and matrix cracking, whereas interlaminar damage mechanisms correspond to the interfacial separation of the individual plies (delamination).



Fibre fracture Transverse matrix crack Delamination

Figure 1 Damage mechanisms in LCS

Delamination is one of the most important and common types of damage in LCS due to their relatively weak interlaminar strengths. The governing stresses for the delamination initiation are the out-of-plane stresses, and in literature usually referred to as interlaminar stresses. Delamination starts generally at the geometrical discontinuities, such as laminate free edges and cut-outs. This is so because the state of stress close to a free edge in a laminate is three-dimensional, with nonzero interlaminar stresses, which grow without bound due to a singularity in the stress field at the intersection of the free-edge and the interface [1]. Delaminations may arise in a LCS under various circumstances, e.g. when subject to transverse concentrated loads, such as low velocity impacts arising from a falling mass, and propagate due to the undergoing loads of the structure such as dynamic loading. Finally the behaviour of the entire structure changes and in most cases a failure is unavoidable.

II. THE CHALLENGE OF NUMERICAL MODELLING

To arrive at a better understanding of damage/delamination phenomena and in order to reduce the design costs of a structure, numerical simulations can be of assistance. A notable effort has been devoted to the numerical and theoretical modelling of the LCS in the last few decades but a number of issues still need to be further investigated.

The incompatibility between the overall dimensions of the LCS (up to 50-60 meters e.g. wind turbine blade) and the thickness of individual composite plies (typically 150-200 micrometers) introduces an additional level of complexity in the numerical modelling. For the linear elastic numerical analysis of a large-scale LCS, Equivalent Single Layer (ESL) shell elements proved to be reasonably efficient and accurate on global scale. ESL shell elements are based on the Lamination Theory (LT), which is used to homogenize the material properties of stacked plies in a laminate. But when it comes to the delamination modelling in LCS, which is rather a local phenomenon, these elements are not suitable, as they are based on the plane stress assumption that renders them incapable of capturing the interlaminar stresses, the root cause of delamination. And the local nature of damage can affect the global response of the composite structure, if the loading conditions are such that the delamination can slowly grow and finally propagate through the structure. To determine the critical stress state in the delamination susceptible areas, a detailed Finite Element (FE) mesh is necessary to enable us to capture the in-plane stresses as well as the interlaminar stresses at the interface between individual plies. On the other hand, if this detailed FE mesh is applied to the whole LCS, the computation would last for months.

III. GOAL

The main goal of this project is to develop a multi-scale global-local FE analysis of LCS. In global-local FE analysis, the global response of the structure is combined with a detailed stress analysis in a particular region of interest , as shown in Figure 2, with integration of the successive simulations for the damage evolution and this in a computationally efficient manner.

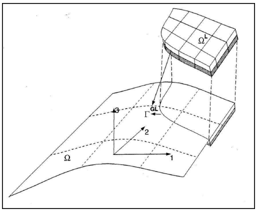


Figure 2 Global-Local FE analysis

The general idea is to use two types of finite elements: (i) a fast-calculating shell element for the major, undamaged part of the composite structure, and (ii) a more computationally intensive element for the damaged regions. The transition from the first element to the latter as damage propagates through the structure, should be made by the finite element software itself in each successive analysis step (depending on critical stress/strain levels, fracture initiation criteria,...), so that the user does not need to know in advance where the damage will initiate and propagate.

REFERENCES

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[2] R.M. Jones, Mechanics of composite materials - second edition, Taylor and Francis, 1998.