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Numerical Methods for Modelling Impact on Composite Structures

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Aircraft structures are prone to impact damage resulting from collision with foreign objects such as runway debris, birds or hail. With the increased application of composite materials in aircrafts, there is a demand for reliable numerical models to support the design process with respect to dynamic impact load cases. In the present study a numerical methodology is presented that aims at modelling the different damage mechanisms and their interactions in macroscopic composite structures subjected to high velocity impact loads.

Impact damage in composite laminates usually is a combination of different damage modes. The typical failure mechanisms are fibre breakage, matrix cracking, fibre/matrix debonding and delamination [1]. Delamination damage is the separation of laminated plies due to the failure of the interfaces between laminas of different orientation. In delaminated areas the transfer of loads between adjacent plies is prevented which can lead to severe reductions in strength and stiffness of the laminate [2]. Choi and Chang [3] outline the delamination initiation process and state that transverse impact induces critical matrix cracks that can propagate along the bottom or upper ply interfaces of the cracked layer.
In the present study the interaction between intra- and interlaminar damage and its effect on the impact response is investigated. The approach adopted here is based on Continuum Damage Mechanics (CDM) where internal state variables are introduced to describe damage processes mathematically [4]. Ladevèze and Ledantec [5] used the framework of CDM to develop a model that captures the internal degradation and rupture behaviour of unidirectional fibre reinforced polymer plies. Stiffness degradation by matrix microcracking, fibre/matrix debonding and brittle fibre failure is modelled by introducing damage variables and energy based damage evolution laws. Johnson et al. [6] successfully implemented Ladevèze theory in the commercial explicit finite element code PAM-Crash. The laminate was then modelled with stacked plane stress shell elements connected with cohesive layers (‘stacked shell approach’) so that delamination as well as ply damage was captured. The frequently used bilinear traction-separation law to simulate delamination, see Figure 1a, is based on the combination of the fracture mechanics technique and CDM introduced by Cui and Wisnom [7]. It applies a strength based damage initiation criterion (σ_{max}) and an energy based crack propagation criterion. The damage initiation stress has to be chosen such that stable crack propagation is achieved which usually leads to a value that is lower than the expected interface strength. This leads to an early failure of the interface which has an effect on the overall impact response of the laminate. The authors propose to initiate interface damage only after the matrix damage in one of the neighbouring plies has reached a critical value (see Figure 1b). This takes into account findings in the literature on the crack propagation

behaviour in composite laminates under impact. Before the critical intra-laminar matrix damage is reached the interface behaves like a linear elastic spring.

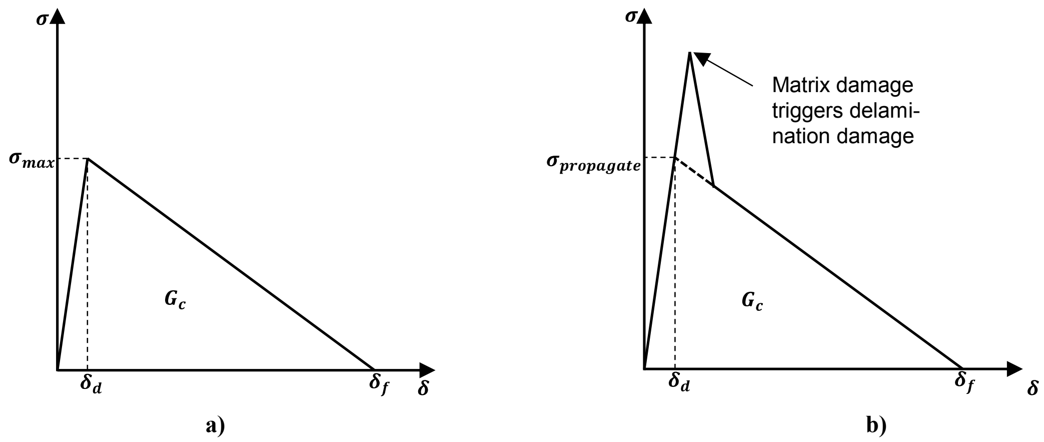

Figure 1: a) Critcal maxtrix cracks and initation of delamination damage [3]; b) Bilnear traction separation law with linear elastic model before damage initiation

The model was implemented in explicit user subroutines within the commercial finite element code Abaqus FEA and then applied to model high velocity impact of a blunt impactor on flat composite plates at impact velocities in the range 70-100m/s. The numerical results were assessed by comparison with experimental data from impact tests at the DLR gas gun test facility. From the numerical simulation it was seen that the interface failure behaviour has a major effect on the impact response of the composite plate. With the matrix damage trigger concept a physics based interface model was implemented to simulate a more realistic delamination crack initation.

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