Higher-order layer-wise models for the progressive damage and impact analysis of composite structures

Manish Hassan Nagaraj

The progressive damage modelling of fibre-reinforced composites is a challenging task owing to the various types of failure mechanisms as well as their interactions. Damage arising due to impact loads on composite structures is of practical interest in the aerospace industry, since such loads can occur frequently during the service life of the composite aerostructure, leading to barely visible impact damage. The use of computational approaches to such a class of problems is likewise challenging, and often involves significant computational effort.

The objective of the present work is the development of a computationally efficient numerical framework for the impact analysis of fibre-reinforced composite structures. The numerical model is developed using higher-order structural theories obtained using the Carrera Unified Formulation (CUF), where additional expansion functions of various types and orders are used to improve the kinematics of classical finite elements. Such an approach leads to 1D and 2D models which provide solutions that are comparable to 3D-FEA, at a fraction of the corresponding computational effort. The current work uses Lagrange polynomials to define the cross-section of 1D elements, and through the thickness of 2D elements, leading to a layer-wise modelling approach. A nonlinear explicit dynamics solver, *CUF-Explicit*, has been developed by combining CUF theories with the central difference explicit time integration scheme. This framework is used for highly nonlinear dynamics problems such as impact analysis. A two-step sequential global-local technique has been developed, which interfaces the CUF-based numerical platform with commercial finite element codes. Various capabilities such as contact modelling and progressive damage modelling have been developed within the CUF framework as part of the present work. The node-to-node and node-to-surface techniques are used for contact surface discretisation,

while the contact constraints are enforced using penalty and Lagrange multiplier approaches. Progressive damage of unidirectional fibre-reinforced composites is modelled using the CODAM2 material model, which is based on continuum damage mechanics. A series of numerical assessments are presented to validate and verify the capability of each development.

The contact and damage modelling capabilities are combined in the CUF-Explicit framework, leading to a CUF-based numerical platform for the progressive damage analysis of composites subjected to low-velocity impact loads. A series of numerical assessments are presented for the verification and validation of the proposed numerical approach for impact problems, and demonstrate the capabilities and advantages of layer-wise CUF models, compared to 3D-FEM, for accurate and computationally efficient impact analysis.