Numerical Simulations of Low-Velocity Impact on Thick Composites

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Introduction

Fibre reinforced composites are nowadays widely used in many technical applications, such as aerospace, sport, automotive or energy due to their advantageous properties, such as their excellent stiffness/weight ratio, resistance to fatigue and corrosion, etc. Nevertheless, these materials present relatively poor damage resistance, which can have dramatic consequences.

Low-velocity impacts may occur during handling, and the damage they could induce and their consequences have to be well understood, especially because they are often difficult to detect with visual inspection.

Experimental investigations allow designers to dimension their parts, but these tests are costly in time and resources. A numerical model able to predict accurately the impact induced damage would be a powerful tool for composite structure design.

The aim of this project is to develop a finite element model to simulate numerically low-velocity impact on thick composite, based on an experimental paper [1]. This model should be able to predict low-velocity induced damage and dynamic response accurately, in order to use this numerical tool to have a better understanding of the experimentally obtained results. This model could then be used to perform analyses that are difficult or impossible to achieve experimentally.

Numerical model

Two types of reinforcements were used: quadiaxial [0°/±45°/±45°/90°] E-glass fibre fabric with a chopped strand mat (CSM) backing (a) and 2/2 twill carbon fabric (b), with epoxy as matrix. Different thicknesses, impact energy level and configuration were tested experimentally and numerically.

The hybrids were composed of 10mm thickness carbon twill with one or two added layers of E-glass. Different damage models were tested, for both inter-laminar damage (delamination) and intra-laminar damage (fibre failure and matrix cracking), depending on the type of composite studied. The different methods tested for the inter-laminar damage model, called cohesive zone models (CZM), are presented here. The final choice for the CZM is the zero-thickness cohesive elements with tie constraints.

During the experimental tests, the samples are clamped on a solid area. Only the solid area of the figure below is modelled. The impactor, solid area under the composite laminate and pins are treated as rigid bodies. The degrees of freedom of the impactor and the pins are restricted to vertical displacement (out-of-plane) only, while all the degrees of freedom of the solid area are blocked.

The contacts between the rigid parts and the composite plies is defined with the general contact algorithm of ABAQUS/Explicit. The normal behaviour is considered as a “hard contact”, and a friction coefficient of 0.3 is applied. Regarding to the geometry of the problem, only the quarter of the system is modelled for computational efficiency.

The mesh size was determined by the damage models. Each of the model has a maximum element length to avoid instabilities and capture the damage accurately. The use of tie-constraints allows to refine the cohesive mesh compare to the one of solid elements.

Carbon / epoxy specimens

The numerical model for carbon specimen agrees well with the observed experimental results, regarding the delamination and the force, as well as the evolution of the different outputs with respect to impact energy and laminate thickness. The drop in the force-time response corresponds to the critical load.

E-glass/epoxy specimens

The results obtained for the E-glass specimens are consistent with each other and with the results of the carbon specimens. However, regarding to the experimental results, the delamination from the numerical model for the E-glass specimen is not satisfying. This composite is more complex than the other one, and the numerical model used is maybe too simple to represent accurately the reality.

Hybrids specimens

Regarding to the experimental samples, it seems that the added E-glass layers concentrates the damage, which seems not to be the case in the numerical model. The numerical model over-estimated the inter-laminar damage compared to experimental cross-sectioned samples. Furthermore, the critical load was under-estimated in the numerical model.

Critical load and damage evolution

This figure shows the evolution of the degradation of the cohesive zone at the critical load. This threshold force does not physically coincide with the initiation of damage, but indicates a sudden stiffness loss caused by instantaneous large delamination due to unstable crack propagation.

In the numerical model, this load is reached after approximately 28ms, and one can observe that it corresponds to the moment when the delamination reaches the bottom of the laminate, i.e. the inter-laminar damage has propagated through the whole thickness of the composite, which explains the sudden stiffness degradation and thus the change of slope in the force-time response.

Conclusions

In this work, the numerical results from the different models have been compared to decide which model was the most appropriate, and then compared to experimental data.

The numerical model used for the carbon twill specimens proved that it was able to reproduce with accuracy the experimental results, through the different impact energy levels and laminate thicknesses. The cross-sectioned delamination showed good agreements with the experiments, even if it was slightly over-estimated in the simulation.

Concerning the E-glass, the numerical results were internally consistent, and the evolution of the outputs with respect of the impact energy was reasonable. However, the obtained results differed from the experimental ones, especially regarding the delamination.

Improvements were obtained when modelling the CSM layer separately from the laminate plies. The hybrids were not predicted accurately compared to experiments; it is attributed to the damage, which seems not to be the case in the numerical model. The numerical model used is maybe too simple to represent accurately the reality.

The hybrids were not predicted accurately compared to experiments, it is attributed to the hybrid composite could be better than monolithic one of the same thickness.

References

[1] Pantelidi, Μ. D., (RMIT), Melbourne, Australia.