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Numerical, Experimental and Analytical Correlation for Predicting the Structural Behavior of Composite Structures Under Impact

F.Di Caprio[a]*, A. Langella[b], V. Lopresto[b], G. Caprino[b]

[a] *CIRA – Italian Aerospace Research Centre, Capua, Italy*
[b] *University of Naples "Federico II" Department of Industrial Engineering - Aerospace Branch, Italy*

Abstract

In the present work, numerical, experimental and analytical results regarding impact events on composite structure are presented. The test case consists in a classic 24 plies CAI specimen (100×150 mm) subjected to 10 J impact. The work can be divided into two phases. The first phase is finalized to the definition of a procedure able to provide a robust numerical model, which can simulate accurately the structural response of composite plates subjected to impact events. At this phase, the numerical results are compared with analytical ones. In the second phase, both inter- and intra-lamina failure are considered. Regarding the inter-laminar failure, an experimental-numerical procedure is defined in order to set the right parameters related to cohesive behaviour. For both phases, trade-off analyses on the main numerical parameters are performed. All numerical results are compared with experimental ones in terms of both energy balance and damaged area.

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1. Introduction

Due to their high specific mechanical properties, fiber reinforced composites are widely used in aerospace applications. The high weight-specific stiffness and strength of composite materials allows for a significant

* Corresponding author. Tel.: +39 0823 623538; fax: +39 0823 623335.
E-mail address: f.dicaprio@cira.it

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reduction of airframe weight. However, despite their excellent in-plane properties, the poor transverse strength of laminated composites makes them prone to damage induced by transverse loading conditions. Therefore, impact loads can cause substantial damage in composite structures, causing a significant reduction of strength and stiffness [1]. Low energy impacts can trigger extensive damage to the fibers and/or to the matrix [2,3], leading to a substantial loss in post-impact strength [4].

Fiber-reinforced polymer composites, especially CFRP, are very susceptible to reductions in strength due to accidental impact damage. In the case of structures subject to compression load, such reduction in strength can be significant and it is typically taken into account in the design phase by adopting conservative material design allowable. For such a reason, it is very important to develop methodologies able to provide useful information regarding the actual damage state of the structure, estimating the capabilities of the component to sustain the operative load.

In the present work, a numerical, experimental, and analytical correlation regarding the impact event on composite structure is presented. The test case is a classic 24 plies CAI specimen (100×150 mm) with a stacking sequence of $[45,-45,0,0,90,0]_{2s}$ subjected to impact at 10J. The two test cases were used to correlate the numerical results with the analytical and the experimental ones. Since the impact at 10 J did not generate significate failure, the specimen subjected to the 10 J impact was used to compare the numerical results to the experimental ones and to the analytical solution, considering a linear elastic behavior of the material. In a first phase different numerical models were considered, assuming different discretizing levels and different element formulations. In particular, the contact algorithm used both for contact between impactor and plate, and between plate and fixture (a rigid support as prescribed by the normative) was investigate. Under this assumptions, a robust numerical model able to simulate accurately the structural response of composite plates subjects to impact event that do not generate failure can be defined. The last can be considered as starting point for more complex analyses. The best model was used in the second phase taking into account both inter-lamina [5-7] and intra-lamina [7,8] failure. The delamination was simulated through a contact surface with cohesive behavior and failure option placed between each sub-laminate [9]. An experimental-numerical procedure was used to define the right parameters related to cohesive surface. Adequate failure criteria were defined for each ply in order to simulate the failure of fiber and matrix (Hashin criteria [10]). A trade-off on all numerical parameters that influence this kind of analysis was performed. All numerical results are compared with experimental ones in terms of both energy balance and damaged area.

2. Numerical model definition

The analyses described are characterized by a huge number of numerical parameters, that can be set assuming a step-by-step methodology.

The first phase consists in the definition of a robust numerical model able to simulate the impact events on composite structure without considering any failure. Hence, only the material elastic behavior has been considered. In such a way, the numerical parameters can be easily set. Several numerical models were defined with increasing complexity level and with different setting of numerical parameters (element size, element formulation, etc.). In this context, for sake of brevity, only the main results are presented. The numerical results, relating to this first phase, were compared with analytical ones. All that, since the experimental tests produced some failure even at 10 J.

In the second phase, after setting the main numerical parameters, inter- and intra-lamina failure option were added increasing the complexity level, but increasing at the same time also the accuracy level.

2.1. Analytical results

Analytical solutions are available in literature for particular cases like rectangular composite plate with simple supported along the edge. The motion of an orthotropic plate is governed by the equation:

$$D_{11}\frac{\partial^4 w}{\partial x^4} + 2(D_{12} + D_{66})\frac{\partial^4 w}{\partial x^2 \partial y^2} + D_{22}\frac{\partial^4 w}{\partial y^4} + D_{16}\frac{\partial^4 w}{\partial x^3 \partial y} + D_{11}\frac{\partial^4 w}{\partial x \partial y^3} + I_1 \ddot{w} = 0 \quad (1)$$