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ScienceDirect

Procedia Engineering 167 (2016) 182 – 189

Procedia Engineering

www.elsevier.com/locate/procedia

Comitato Organizzatore del Convegno Internazionale DRaF 2016, c/o Dipartimento di Ing. Chimica, dei Materiali e della Prod.ne Ind.le

Compression After Impact Analysis of Composite Panels and Equivalent Hole Method

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Abstract

The necessity to exploit the full potential of the composite materials in aviation has stimulated in the last two decades the development of the Progressive Failure Analysis methodology. This kind of analysis foresees discrete damages that are introduced in the finite element model of the structure by preserving the full mechanical strength properties of the material. Since the numerical analysis of the impact event is very expensive, simplified damage models are commonly used in the preliminary design phase; the degradation of the strength due to a Barely Visible Impact Damage is considered equivalent to that one due to a 1/4 inch hole diameter. In this work, the above mentioned equivalence has been studied by experimental compression tests and numerical analyses on impacted and notched composite coupons. After the validation of the numerical models by the Progressive Failure Analysis, the hole diameter equivalent, in terms of residual strength, to the experimental impact damage, has been numerically evaluated considering different holes sizes up to 1 inch. The computed equivalent hole diameter, found at coupon level, has been considered in the subsequent numerical simulations concerning the skin of a 2-stringer panel, in order to verify the validity of the equivalence damage-hole also at panel level. The preliminary results of this work show that the possibility to simulate the Barely Visible Impact Damage with an equivalent hole, if completely demonstrated, could simplify the future numerical analyses of impact damaged laminates. The activity performed in this work is preparatory to the development of the design methodologies that are under investigation in the European project Airgreen 2 within the frame of Clean Sky 2.

Peer-review under responsibility of the Organizing Committee of DRaF2016

Keywords: Composite; Damage; Impact; Residual Strength; Hole.

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Peer-review under responsibility of the Organizing Committee of DRaF2016
doi:10.1016/j.proeng.2016.11.686

1. Introduction

The high sensitivity of composite materials to damage and defects, in particular low energy impact damage (BVID), limits the exploitation of the full potential of these materials in the aeronautical field, leading to oversized aircraft components. The necessity to overcome this limit and to exploit the full potential of the composite materials, has encouraged in the last two decades the development of new advanced numerical methodologies, named Progressive Failure Analysis, that is based on FEM, and aimed to predict the actual capability of composite structures in presence of discrete damages. The PFA methodology, founded on implicit solution methods and nonlinear analysis, is finalized to predict, in addition to the damage initiation (FPF), the damage propagation up to the collapse load of a composite structure, in order to fully exploit the real residual strength of impact-damaged structures [1-3]. This kind of analysis foresees a discrete damage that is introduced in the FE model of the structure and by preserving the full mechanical strength properties of the material, differently from the conservative traditional design approach, consisting on FPF and by considering the structure wholly damaged (BVID knock-down factor application). Generally, in order to determine the strength of an impacted panel, it is mandatory to simulate, firstly, the impact event, and then the compression test. The numerical analysis of the impact event is very expensive; consequently, in order to avoid computational intensive analysis methods that model damage initiation and its evolution under load, simplified damage models are commonly used in the preliminary design phase. According to some industrial design guidelines, mainly issued by Northrop Grumman [4-6], in the preliminary design phase it is possible to consider the degradation of the strength due to a BVID, as equivalent to that one due to a 1/4 inch (6.35 mm) hole diameter. In this work, the above mentioned equivalence in terms of residual strength has been studied by performing CAI tests for different impact energy levels on two selected laminates (100 mm x 150 mm), and also compression tests on coupons of the same CAI geometry but with 1/4 inch central hole. A carbon fiber resin epoxy system, commonly used for aeronautical applications, has been considered (unidirectional prepreg tape). PFA analyses have been performed to simulate the compression test on the impacted and open-hole coupons in order to validate the numerical models, the numerical methodology and approach: in particular, the failure criteria selection, the material property degradation model, the nonlinear iteration method, the load stepping procedure, etc. The PFA has been performed by using the progressive failure analysis MSC Nastran® capability.

After the above validation, the hole diameter equivalent to the experimental impact damage has been numerically evaluated; different holes sizes up to 25.4 mm (1 inch) in diameter have been considered to evaluate the hole able to ensure the same residual strength of the impact test. The computed equivalent hole diameter, found at coupon level, then has been considered in numerical simulations concerning the skin of a 2-stringer panel. The validity of the equivalence BVID-hole has been verified also at panel level for the same material system.

This work shows the great potentiality of the PFA as design tool and the possibility in the future to simplify the numerical models and analyses to predict low energy impact effects with high computational time savings.

Nomenclature

BVID	Barely Visible Impact Damage
CAI	Compression After Impact
CBI	Compression Before Impact
CU	Compressive Ultimate
FE	Finite Element
FEM	Finite Element Method
FPF	First Ply Failure
PFA	Progressive Failure Analysis
TF	Total Failure