Available online at www.sciencedirect.com
ScienceDirect
Composite Structures 82 (2008) 217–224
COMPOSITE STRUCTURES
www.elsevier.com/locate/compstruct

Degradation investigation in a postbuckling composite stiffened fuselage panel

A.C. Orifici [a], R.S. Thomson [b,*], R. Degenhardt [c], A. Kling [c], K. Rohwer [c], J. Bayandor [d]

[a] School of Aerospace, Mechanical and Manufacturing Engineering, Royal Melbourne Institute of Technology, GPO Box 2476V, Melbourne, Vic. 3001, Australia
[b] Cooperative Research Centre for Advanced Composite Structures Limited, 506 Lorimer Street, Fishermans Bend, Vic. 3207, Australia
[c] Institute of Composite Structures and Adaptive Systems, DLR – German Aerospace Center, Lilienthalplatz 7, 38108 Braunschweig, Germany
[d] The Sir Lawrence Wackett Centre for Aerospace Design Technology, Royal Melbourne Institute of Technology, GPO Box 2476V, Melbourne, Vic. 3001, Australia

Available online 13 January 2007

Abstract

COCOMAT is a four-year project under the European Commission 6th Framework Programme that aims to exploit the large strength reserves of composite structures through a more accurate prediction of collapse. Accordingly, one of the COCOMAT work packages involves the design of test panels with a focus on investigating the progression of composite damage mechanisms. This paper presents the collaborative results of some of the partners for this task. Different design alternatives were investigated for fuselage-representative test panels. Non-linear structural analyses were performed using MSC.Nastran and ABAQUS/Standard. Numerical predictions were also made applying a stress-based adhesive degradation model, previously implemented into a material user subroutine for ABAQUS/Standard. Following this, a fracture mechanics analysis using MSC.Nastran was performed along all interfaces between the skin and stiffeners, to examine the stiffener disbonding behaviour of each design. On the basis of the structural and fracture mechanics analyses, a design was selected as being the most suitable for the experimental investigation within COCOMAT. Though the COCOMAT panels have yet to be manufactured and tested, experimental data on the structural performance and damage mechanisms were available from a separate project for a panel identical to the selected design. This data was compared to the structural, degradation and fracture mechanics predictions made using non-linear finite element solutions, and the application of the design within the COCOMAT project was discussed.

Keywords: Composite; Buckling; Postbuckling; Stiffened panels; Skin–stiffener disbonding; COCOMAT

1. Introduction

The European Commission specific targeted research project "Improved **MAT**erial Exploitation at Safe Design of **CO**mposite Airframe Structures by Accurate Simulation of **CO**llapse" (COCOMAT), is a currently running four-year project involving 15 international partners that aims to exploit the large strength reserves of postbuckling composite stiffened panels [1,2]. Currently, the onset of degradation in composite materials is not allowed, and composite structures must be designed with degradation occurring after the design ultimate load. The focus of COCOMAT is to produce a validated approach to include the effects of material degradation in the analysis, so that the final collapse of the structure can be more accurately predicted. This will allow composite structures to be designed with some degradation permitted, in a manner comparable to metallic structures where plasticity is already allowed between limit and ultimate loads. COCOMAT benefits from a high degree of synergy with the recently completed European Commission Framework Programme 5 project "Improved **PO**st-buckling **SI**mulation for Design of Fibre **CO**mposite **S**tiffened Fuselage

* Corresponding author. Fax: +61 3 9676 4900.
E-mail address: r.thomson@crc-acs.com.au (R.S. Thomson).

0263-8223/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compstruct.2007.01.012

Structures" (POSICOSS), which similarly investigated the behaviour of fuselage-representative stiffened composite panels in compression, but did not include the effects of material degradation.

One of the work packages of the COCOMAT project is the design of fuselage-representative panels for experimental testing. Within this work package, the German Aerospace Center (DLR) and the Cooperative Research Centre for Advanced Composite Structures (CRC-ACS) are collaborating to produce panel designs with a specific focus on the experimental investigation into skin–stringer disbonding. This paper outlines the results of the collaborative research work so far, which includes the selection of a design most appropriate for the investigation of skin–stringer disbonding based on structural and fracture mechanics analyses. Though COCOMAT panels have not yet been manufactured and tested, a comparison is made between the numerical predictions and experimental testing data for an identical panel from a separate project.

2. Panel design

2.1. Panel variations

Based on previous experience [3], a nominal panel was defined, and three variations were proposed. These variations, V12, V15 and V16 all used identical material and boundary conditions, though had slight variations in geometry in order to investigate the effect of the number of stiffeners and the height of the outer stiffeners, see Fig. 1 and Table 1. The V12 design used four stiffeners with the outside two made 6 mm (43%) taller and stiffer than the nominal design, whereas the V15 and V16 design both used the nominal stiffener size, but differed in using five and six stiffeners, respectively. Finite element (FE) models were generated for ABAQUS/Standard (Abaqus) and MSC.Nastran (Nastran), and are summarised in Table 2. The boundary conditions for all models were identical, with the axially loaded and fixed ends both fully clamped, and the resin-embedded or "potted" region on both ends represented as an area in which only axial displacement was permitted, based on work by previous authors [3,4]. The main difference between the Abaqus and Nastran models was in the representation of the skin–stiffener interface, where the Nastran models used only rigid links to connect the elements in the skin and stiffener flange, while the Abaqus model used rigid links connected to a thin layer of solid elements between the skin and flange to represent an adhesive layer.

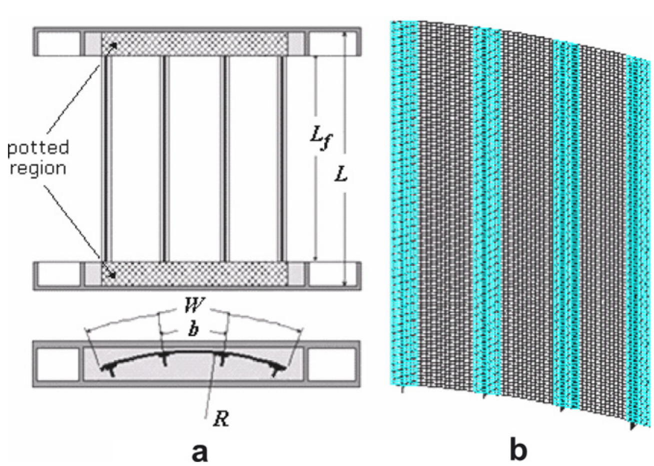

Fig. 1. Nominal panel design (a) geometry and (b) Abaqus FE model.

2.2. Analysis approach

The three panel variations were analysed with implicit solvers using a full Newton–Raphson procedure [5], where the default non-linear parameters of both software packages were used, except for a STABILIZE parameter of 2×10^{-6} in Abaqus and a convergence tolerance level of "Very High" in Nastran. The STABILIZE parameter functions similar to a viscosity in Abaqus, where the addition of the factor reduces some of the energy of the panel to assist with convergence issues, and the "Very High" setting in Nastran corresponds to load and work residuals of 1×10^{-3} and 1×10^{-7}, respectively. All panels were analysed to 4 mm axial compression, except for the Nastran V15 and V16 models, which only ran to 3.54 mm and 3.51 mm axial compression, respectively due to convergence problems.

For the Nastran models, use was made of a tool developed previously, Compdat [6], to calculate strain energy release rates (G) at all the skin–stiffener interfaces. The values of G in its modes I and II components were used in a mixed-mode failure law, given in Eq. (1), to determine the likelihood of skin–stiffener disbond initiation. In order to do this, values of G_{Ic} and G_{IIc} for the IM7/8552 material system were required, which were taken from Schön et al. [7,8], and are given in Table 3. The stiffeners in each panel were numbered starting from the topmost stiffener, as viewed in the XY plane, and skin–stiffener interfaces were designated as upper or lower for each stiffener in the same plane. The numbering system for all models is given in Fig. 2, where S is the stiffener number, I is the interface designation, and U and L are upper and lower, respectively. For each model, the sensitivity of the disbond predictions to the exponents of the mode I and II ratios m and n in Eq. (1), respectively) in the mixed-mode failure law was also investigated.

$$\left(\frac{G_{\mathrm{I}}}{G_{\mathrm{Ic}}}\right)^m + \left(\frac{G_{\mathrm{II}}}{G_{\mathrm{IIc}}}\right)^n \leqslant 1. \qquad (1)$$

2.3. Analysis results

The load-shortening graphs for designs V12, V15 and V16 are given in Figs. 3–5, respectively. The agreement between Nastran and Abaqus results was very good, particularly for the local buckling. All designs were predicted to buckle into the same local buckling mode shape at an axial