The use of damage as a design parameter for postbuckling composite aerospace structures

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Abstract

Advanced fibre-reinforced polymer composites have seen a rapid increase in use in aircraft structures in recent years due their high specific strength and stiffness, amongst other properties. The use of postbuckling design, where lightweight structures are designed to operate safely at loads in excess of buckling loads, has been applied to metals for decades to design highly efficient structures. However, to date, the application of postbuckling design in composite structures has been limited, as today's analysis tools are not capable of representing the damage mechanisms that lead to structural collapse of composites in compression. The currently running four-year European Commission Project COCOMAT [1] is addressing this issue, and aims to exploit the large strength reserves of composite aerospace structures through a more accurate prediction of collapse.

A methodology has been developed to analyse the collapse of composite structures that is focused on capturing the critical damage mechanisms. One aspect of the methodology is a global-local analysis technique that uses a strength criterion to predict the initiation of interlaminar damage in intact structures. Another aspect of the approach was developed for representing the growth of a pre-existing interlaminar damage region, and is based on applying multi-point constraints in the skin-stiffener interface that are controlled using fracture mechanics calculations. A separate degradation model was also included to model the in-plane ply damage mechanisms of fibre fracture, matrix cracking and fibre-matrix shear that uses a progressive failure approach. The complete analysis methodology was implemented in MSC.Marc v2005r3 using several user subroutines, and has been validated with a range of experimental tests, including fracture mechanics coupons [2], single-stiffener specimens [3] and multi-stiffener curved panels [4].

The developed methodology was used to design and analyse fuselage-representative composite panels in various pre-damaged configurations. Two panel designs were investigated, D1 and D2, which both consisted of a curved skin adhesively bonded to blade-shaped stiffeners. For the D1 panel, the pre-damage applied was a full-width skin-stiffener debond created using a Teflon insert in the adhesive layer, whilst the D2 panel was investigated with Barely Visible Impact Damage (BVID). For both panels,

parametric studies were conducted using the developed methodology in order to recommend a damaged configuration suitable for experimental testing. For the D1 panel, a 100 mm length debond was selected, and the location of the damage was investigated, whilst for the D2 panel both the location and the representation of damage was varied. Based on these parametric studies, two pre-damaged configurations of the D1 panel and one pre-damaged D2 configuration were selected for experimental testing.

The selected pre-damaged configurations were manufactured by Aernnova Engineering Solutions and manufactured at the Institute of Composite Structures and Adaptive Systems at the German Aerospace Center (DLR) as part of the COCOMAT project. Following manufacture, panel quality was inspected with ultrasonic and thermographic scanning and panel imperfection data was measured using the three-dimensional (3D) optical measurement system ATOS. During the test, measurements were taken using displacement transducers, strain gauges, the 3D optical measuring system ARAMIS, and optical lock-in thermography. Under compression, the panels developed a range of buckling mode shapes, and the progression of damage was monitored leading to structural collapse.

In comparison with the experimental results, the analysis methodology was shown to give accurate predictions of the load-carrying behaviour, damage development and collapse load of both panels. The results demonstrated the capability of the developed tool to capture the critical damage mechanisms leading to collapse in composite structures. The advanced analysis methodology also allowed for damage to be used as a design parameter in postbuckling structures, either in the comparative analysis context of a design procedure, to assess the damage tolerance of a design, or as pre- and post-test simulations of intact and pre-damaged structures. More broadly, the results demonstrated the potential of postbuckling composite structures, and the large strength reserve available in the postbuckling region. The success of the developed analysis methodology and the potential of postbuckling composite structures have application for the next generation of lightweight aerospace structures.

References

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