An industrial solution to simulate post-buckling and damage

The SAMCEF finite-element code provides solutions for modelling and analysing post-buckling in composite structures. Post-buckling results in large transversal displacements, which means that a reliable non-linear procedure is required. Ply and interface degradation models can be used to more accurately predict the complex structural behaviour of the composite structure up to the final point of collapse. This paper presents the numerical results obtained as part of research conducted under the COCOMAT European project. Comparison with experimental results shows that SAMCEF accurately predicts the damage mechanisms, panel behaviour and collapse load.



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The COCOMAT European project

Composite materials are increasingly used in modern aeronautical structures. Complex structural analyses are required to help reduce part weight, exploit reserves and propose safe designs. Advanced simulation tools are useful for identifying new design scenarios, bringing the ultimate and collapse loads as close together as possible to improve the operating range of the structural components (Figure 1). COCOMAT is a European project that started in 2004 and ended in 2008. The goal of this project was to develop improved, reliable procedures to quickly analyse post-buckling and collapse in stiffened fibre composite panels intended for future fuselage structures, while taking material degradation into account.

SAMCEF for non-linear analysis of composite panels

SAMCEF Mecano is an implicit finite-element code that can take into account large deformations, large displacements and large rotations. Over the years, it has proved efficient in simulating post-buckling structural behaviours with either a static or dynamic solution procedure.

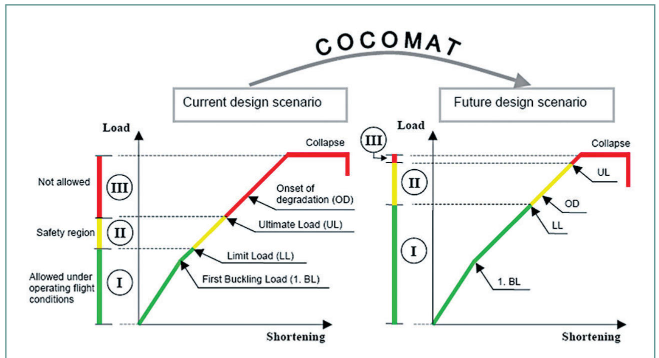

Fig. 1: Current and future design scenarios for typical stringer-stiffened composite panels.

Three main modes of failures can appear in composites: delamination, matrix cracking and fibre breaking. Delamination is an inter-laminar failure which results in the separation of adjacent plies. This phenomenon appears close to holes, ply-drops, free edges, or more generally in regions where a three-dimensional state of stress exists. Cohesive element models are available in SAMCEF to simulate this effect. For intra-laminar failures, such as matrix cracking and ply breaking, a specific material model has been developed. This model can predict fibre-related damage, as well as damage in the transverse and shear directions of the matrix. Non-linearities can also be introduced in the fibre direction. Finally, this model can be coupled to plasticity with isotropic hardening.

Industrial test case

A stiffened composite panel subjected to compression was considered in this industrial case. Figure 2 shows both the physical prototype and the finite-element model. The non-linear procedure in SAMCEF was used to identify the equilibrium path of the structure up to collapse. In order to highlight their impact on the model reliability, different material properties were assigned to the plies and the interfaces.

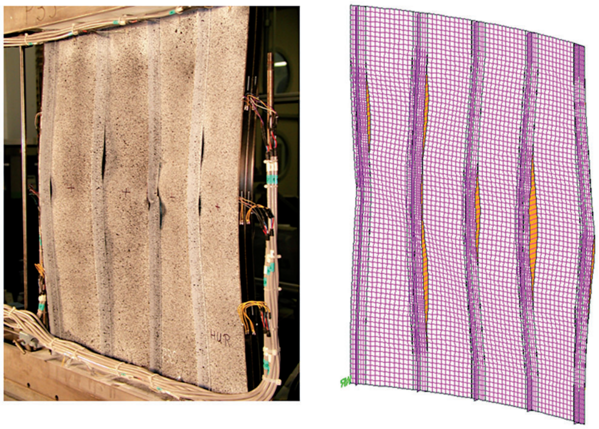

Fig. 2: Physical and virtual prototypes.

In the first model (a), the material degradation is not taken into account; the plies exhibited linear elastic material properties and the interfaces were perfect and elastic.
In the second model (b), the plies were linearly elastic and the interfaces were imperfect. Delamination was therefore taken into account and inter-laminar cracks were able to propagate during the loading stage, especially between the stiffeners and the panel.
In the third model (c), the interfaces were linearly elastic, however intra-laminar damage can appear (fibres breaking and matrix cracking).
In the final model (d), both plies and interfaces were damaged during the loading stage.

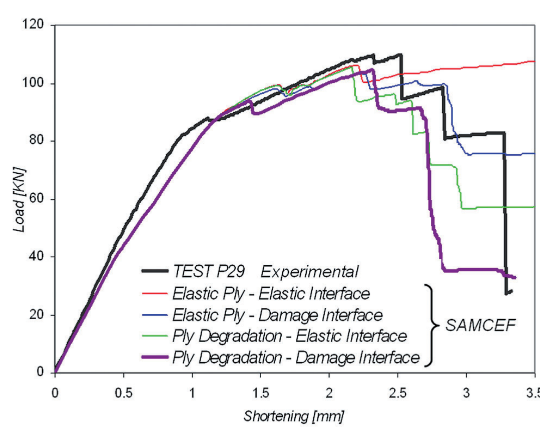

Fig. 3: Comparison of experimental and numerical results.

When compared with the experimental curve (Figure 3), it is clear that the four models present different levels of reliability.

More information ...

In addition to advanced non-linear analysis, optimisation techniques can also be used to improve the design of aircraft components. Semi-analytical sensitivity of the collapse loads was developed in SAMCEF as part of the COCOMAT project. It is used in the BOSS Quattro task manager and optimisation toolbox, together with buckling sensitivity, to determine minimum-weight stiffened composite panels offering the desired buckling and collapse levels.

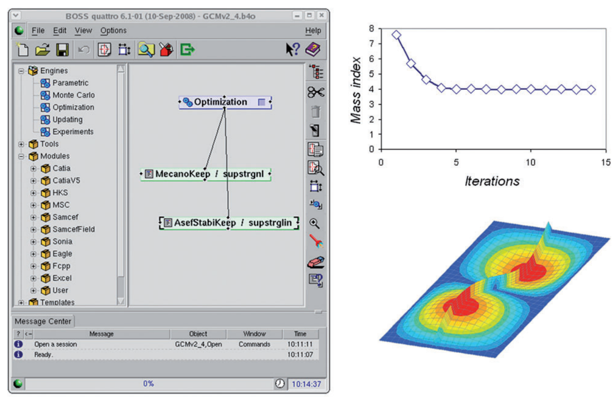

Fig. 4: The BOSS Quattro software developed by SAMTECH to optimize composite structure design.

When material degradation is not taken into account in the finite-element model, numerical analysis does not follow the experimental curve after the collapse load has been reached, resulting in a poor estimation of the structure's post-critical behaviour. While the structural stiffness and strength clearly decrease according to the experiment, the first model (a) with perfect (linear elastic) material properties shows an equilibrium path which is unaltered after the collapse load. When material degradation is allowed to occur, the virtual prototype provides very realistic results, especially when both inter- and intra-laminar damage is modelled (model d). Material non-linearities and damage are therefore necessary to accurately predict the structural behaviour of composite structures. ■

More information: www.samcef.com
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