An industrial solution to analyse delamination

The SAMCEF finite element code proposes solutions to model and analyse delamination in composite structures. Two approaches based on fracture mechanics and on the damage theory are presented here, with an illustration of interlaminar crack propagation under static loading on an industrial application.

Michaël Bruyneel,
R&D engineer, Project Manager

Didier Granville,
Chief Marketing Officer
SAMTECH s.a.

With their high stiffness-to-weight ratio and their anisotropic properties, composite materials are used widely in different sectors such as energy, marine, automotive, building & construction, and, of course, aeronautics. One of the predominant failure modes in multi-ply composites is delamination, resulting from a separation of adjacent layers at locations sensitive to transverse effects. If the number of cracks initiated is high, the overall mechanical properties of real-life laminated structures can be diminished. This is especially true for aerospace structures made of thin panels with co-cured or adhesively bonded frames and stiffeners. To provide safe components, it is therefore mandatory to take those flaws into account in the design phase (figure 1) and to check structural integrity while they propagate.

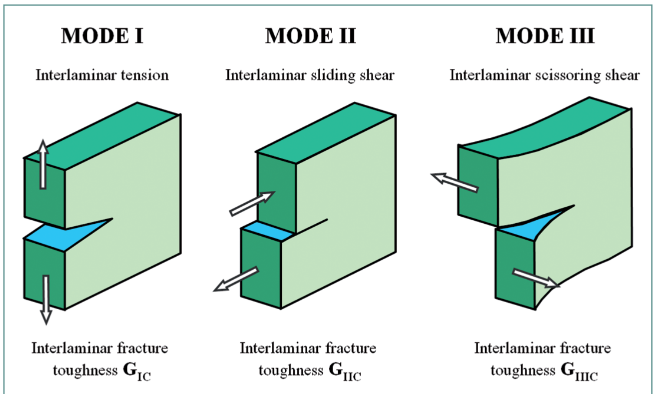

Fig. 1: The three modes of crack extension

However, assessing the damage tolerance of composite structures is clearly a challenge. On the other hand, using virtual testing reduces the number of physical prototypes required and the lead time.

The SAMCEF finite element code offers solutions to simulate and analyse delamination in composites. Here, only the case of static loading is discussed.

The virtual crack extension method

The first approach available in SAMCEF to assess the delamination risks consists in using fracture mechanics in a (possibly linear) static analysis. The strain energy release rates by mode, GI, GII and GIII, are computed with the Virtual Crack Extension (VCE) method as explained in figure 2.

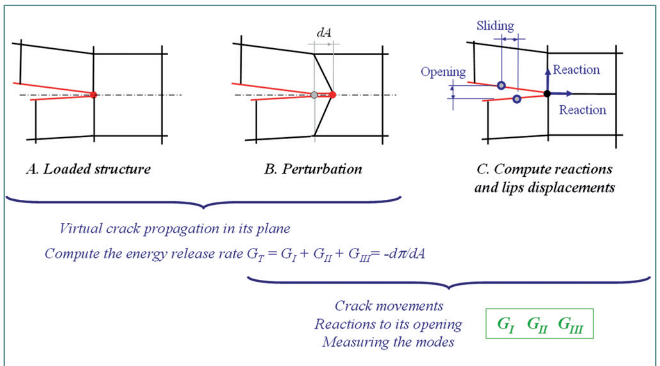

Fig. 2: Principle of SAMCEF's VCE method

The variation in total potential energy π with respect to a given virtual crack surface increment dA is first computed for the current (equilibrium) displacement field via a semi-analytical sensitivity analysis. This provides the total energy release rate GT, which is a measure of the way the stiffness drops when a crack propagates. Then, the contribution to the three individual modes is measured, based on the relative movements of the lips during loading and on the reactions against crack propagation. By comparing these values to the interlaminar fracture toughness, GIC, GIIC and GIIIC, based on some criteria, the critical cracks can be identified and the related propagation load can be estimated (figure 3).

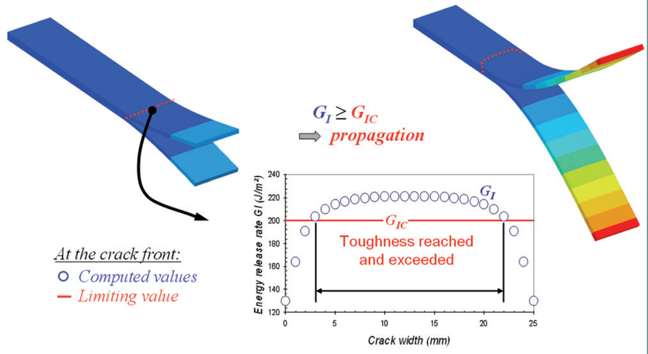

Fig. 3: Estimating the risk of interlaminar crack propagation in a composite structure

The cohesive elements approach

In the second approach, fracture mechanics is used in conjunction with an interlaminar damage model. In order to represent this possible interlaminar damage, a thin layer is inserted between two plies of the laminate, as depicted in figure 4. A specific non-linear softening law is assigned to the material in this thin layer, and its stiffness and strength can decrease down to zero over the loading period, simulating a decohesion between the plies. A bi-triangular material law is presented in figure 4.

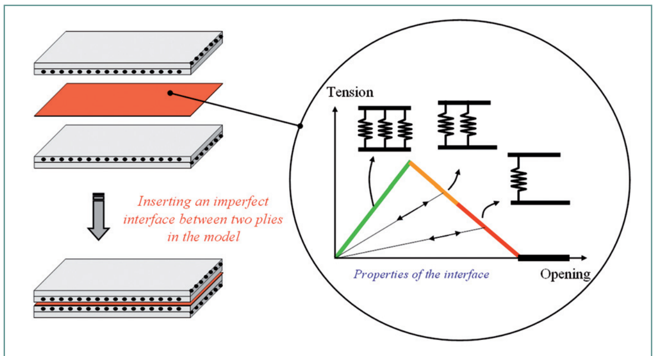

Fig. 4: The interface element and its behaviour under loading

Polynomial and exponential laws are also available in SAMCEF. At the expense of a non linear analysis, this strategy allows estimating not only the propagation load but also the maximum load and the residual stiffness during the fracture process (Figure 5).

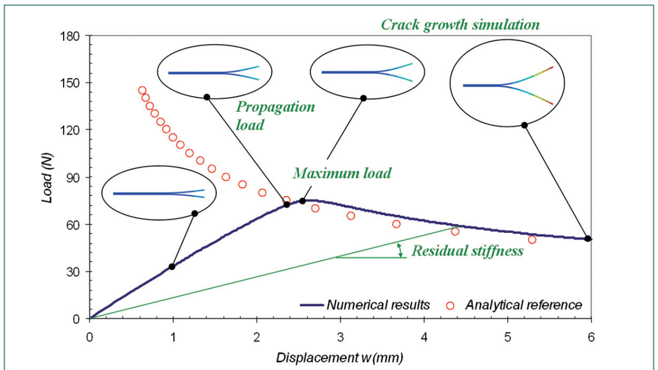

Fig. 5: Estimating the propagation of interlaminar damage by the cohesive elements approach in a DCB

Industrial case studies

A first multi-delaminated stiffened composite structure is considered (figure 6). It includes nine crack fronts defined over the whole length. A force is imposed on the top of the stiffener, and the energy release rates by mode, GI, GII and GIII, are computed and included in a failure criterion.

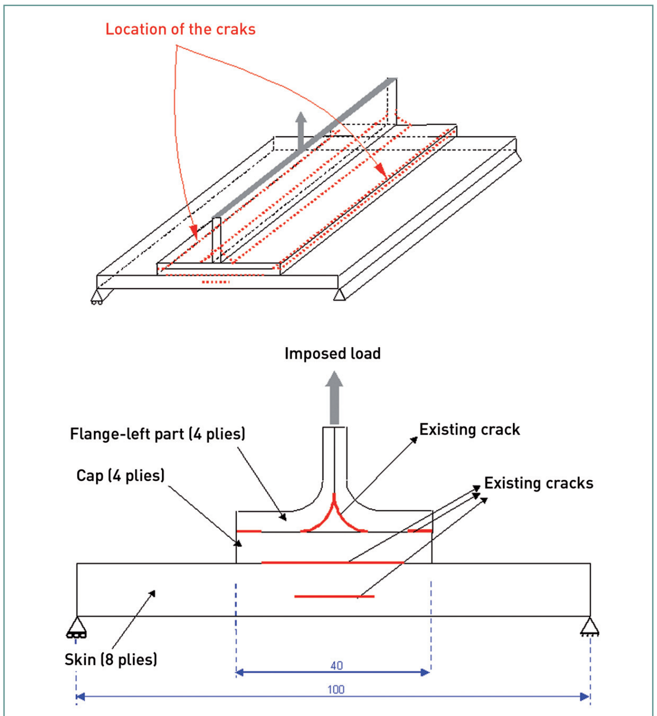

Fig. 6: Defining the problem for the VCE method

The evolution of this failure criterion is illustrated in figure 7. When its value reaches 1, a crack propagation occurs. In our example, it can be observed that cracks 2 and 3 are the most critical ones.

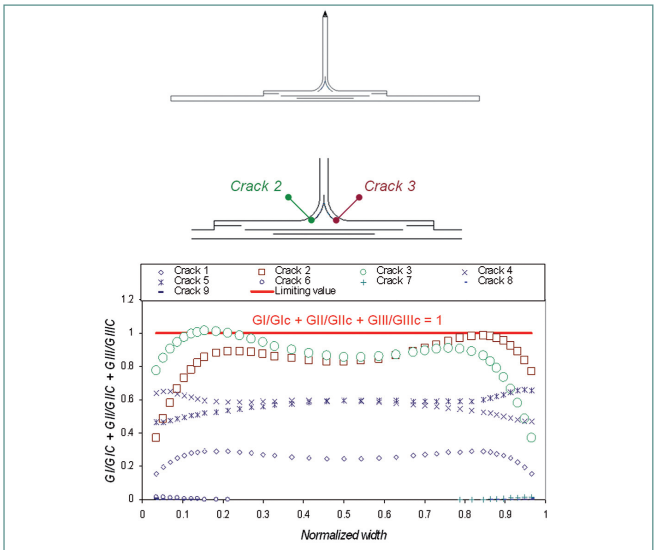

Fig. 7: Solution with the VCE method

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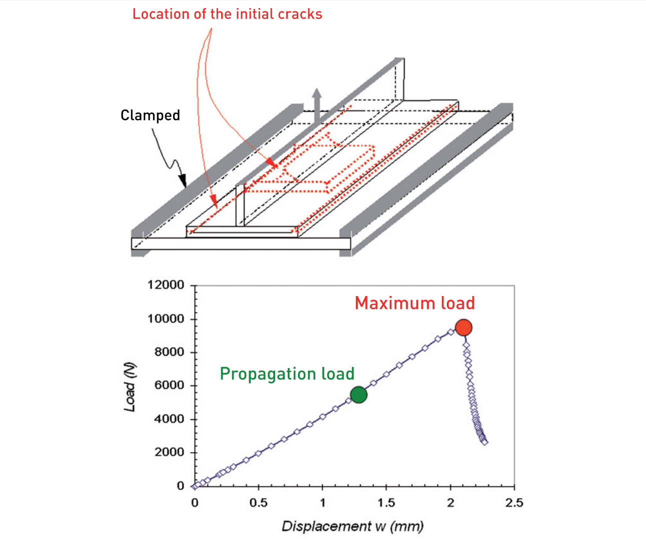

Fig. 8: The T-stiffened panel with the initial cracks, and the load-displacement curve

We now consider a second multi-delaminated stiffened composite panel that includes 55 initial crack fronts between each skin ply and at noodle location, and two large cracks between the cap and the stiffener flanges (figure 8). Here, the cohesive elements approach is used to analyse the propagation of interlaminar damage. A displacement is imposed on the upper part of the T-stiffener.

The load-displacement curve resulting from the simulation is provided in figure 8, where the maximum allowable load before a significant loss of overall stiffness can be estimated. The structural displacements and the extension of damage over the loading are illustrated in figure 9.

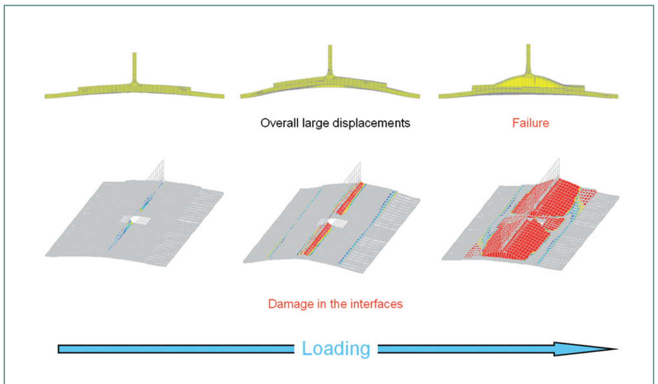

Fig. 9: Displacements and damage propagation over the loading period

Discussion

Modelling and solving delamination problems in composites are known to be difficult, and the virtual testing capabilities offered by SAMCEF comply with the industrial reality.

Some of the needs that have been identified at the industrial level include using large-size finite element models to efficiently represent reality; taking a large number of cracks in the structure into consideration in order to provide a safe design; modelling contact conditions over large areas; and obtaining accurate results.

SAMCEF efficiently answers these industrial concerns with features such as easy definition of cracks and delamination zones; quick estimation of the propagation load via the VCE method; more advanced capabilities through the cohesive elements approach for interlaminar cracks propagation and estimation of the overall structural behaviour during the fracture process; a library of softening material laws for interlaminar behaviours; efficient strategies for treating contact conditions; accurate results (compared to reference solutions); and a parallel solution procedure for large-scale problems. ■

More information: www.samcef.com

More information ...

SAMCEF uses a range of methods to simulate composites, including:

-a comprehensive library of dedicated multi-layered elements,
-a wide variety of material models and structural analyses,
-dedicated pre- and post-processing procedures.

Additionally, BOSS Quattro and its reliable optimisation algorithms help the engineer design a composite structure taking into consideration damage tolerance, amongst other things (figure a).

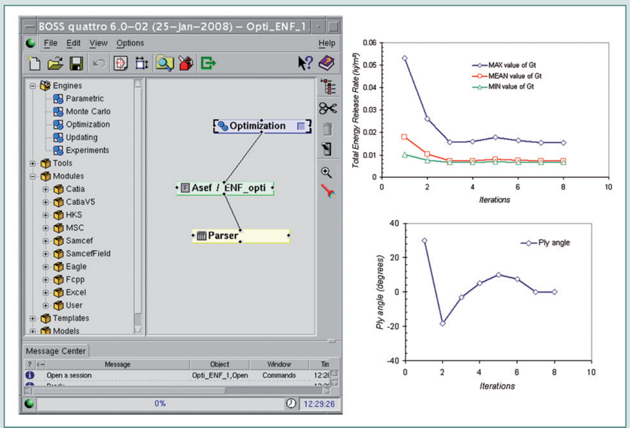

Fig. a: The BOSS Quattro software developed by SAMTECH for designing composite structures