Validation of the SAMCEF material models for inter and intra-laminar damages in laminated composites made of NCF plies

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In order to propose predictive simulation tools, it is important to use material models able to represent the different modes of degradation of the plies forming the laminated composite structure. Damage at the interface between the plies, that is delamination, must also be taken into account in the model. Inter and intra-laminar damages in laminated composites made of bi-axial NCF plies are considered here. The numerical experiences are conducted with the SAMCEF finite element code. Simulation is compared to experimental results, and validations are done at the coupon level and at upper stages of the pyramid of tests.

The material model for the intra-laminar damage is based on the continuum damage mechanics approach initially developed by the Ladevèze's team in Cachan. The laminate is made of homogenous plies. Damage variables impacting the stiffness of each ply are associated to the different failure modes, representing the fiber breaking, matrix cracking and decohesion between fibers and matrix. The specific damage model is first presented. Then, the basics of the parameter identification procedure of such a material model are briefly explained. This procedure is based on test results at the coupon level, and allows determining not only the elastic properties but also the value of the parameters describing the non-linear behavior of the material. The obtained values are then validated on a comparison between test and simulation on a coupon with a stacking sequence not used for the identification.

The cohesive elements approach is used for modeling the inter-laminar damage. The approach is also based on the continuum damage mechanics in a formulation initially developed by the Ladevèze's team in Cachan. A damage model is assigned to some interface elements inserted between plies to represent their possible de-cohesion and a fracture criterion is used to decide on the inter-laminar crack propagation. Using such cohesive elements in the analysis allows estimating not only the propagation load but also predicting the crack propagation and the residual stiffness and strength during the fracture. The inter-laminar damage model is presented together with the basics of the parameter identification procedure relying on DCB and ENF tests.

In this paper, it is also demonstrated that, in general applications, modeling delamination alone is not enough, which means that it is essential to model the damage inside the plies besides the damage at the interfaces. This is illustrated for the ENF test case in which simulation is compared to analytical solutions and test results. It is seen that when only 0° plies are considered, the behavior is quasi-linear up to the crack propagation load, which is the first maximum point of the displacement/reaction curve. However, when 45°/-45° plies are considered, the non-linear behavior observed in the tests can only be reproduced if the damage inside the plies is modeled besides delamination. We note in that case a very good agreement between tests and simulation.

The linear and non-linear material properties identified at the coupon level are then used at the upper stage of the pyramid, on e.g. a L-shaped beam and/or a CAI test case. Comparison between tests and simulation demonstrated the predictability of the modeling and analysis approach.