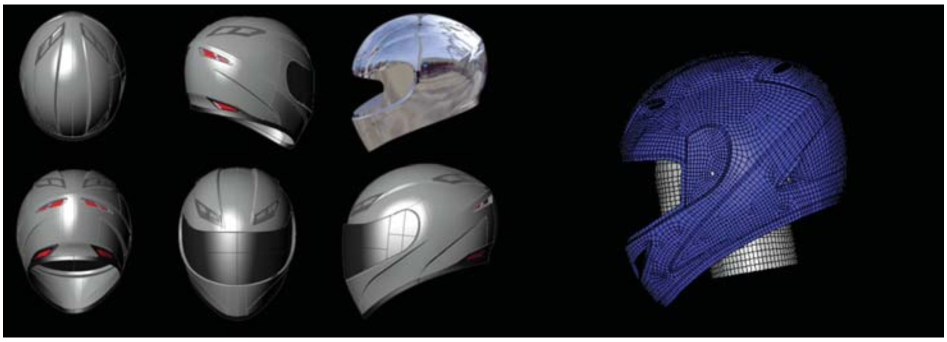
Calibration and experimental validation of LS-DYNA composite material models by multi objective optimization techniques

Numerous authors have documented efforts over the past two decades to understand the complex behavior of laminated composite structures under transient loading conditions. These efforts were made to identify and characterize the relevant failure mechanisms, to understand their interactions, and to be able to predict the extent of damage within a given composite system under a set of specified loading conditions. These studies identify some parameters as basic design parameters, i.e. material parameter (matrix, reinforcement and interfaces between layers), stacking sequence, laminate thickness, striker geometry.

Complexity increases when using a virtual prototyping approach, where the accurate comparison of simulation results with experimental material results is crucial to represent real material behaviour and to achieve optimum. A new virtual prototyping procedure is defined in order to take advantage of numerical prediction and cost-efficient simple material experimental tests for model calibration. In fact, calibration of material models, able to reproduce the effective impact behaviour of real composite materials, is essential in order to simulate impact or crashworthiness problems. It allows either to understand variable influences on composite dynamic structural responses or to get improved performance solutions for industrial case studies. Furthermore, this approach permits to comprehend the effects of non-physical numerical input parameters on a composite structural response in terms of numerical robustness, accurate prediction and computational efficiency of numerical models. A virtual prototyping procedure using a parametric numerical model can be used as well for the product optimization phase that needs a multi-objective and multi-disciplinary approach for composite structures.
The virtual prototyping procedure requires numerical investigations performed by LS-DYNA which has been developed especially for impact and non-linear dynamic simulations, in combination with the multi-objective and multi-disciplinary integrated platform modeFRONTIER employed for the calibration and optimization actions.
In this example, the virtual prototyping procedure is tested to design (and to predict reliability crashing behavior of) motorcycle protective equipments: PTW helmet experience is shown.
Experimental quasi-static tensile and impact tests (usually used for evaluating basic mechanical characteristics and energy adsorption capabilities) were conducted over two different simple square samples of composite laminates, and four different types of sandwich laminates, in order to calibrate LS-DYNA composite material numerical models: starting from and based on the material physical properties derived from the test results.
LS-DYNA model parameters, model constrains and objectives defining the problem have been studied and analysed by using modeFRONTIER.
modeFRONTIER allows to handle a huge number of information deriving from different sources, and to obtain quickly the best model configuration comparison to experimental ones. The tool permits to understand the effect of inputs, to find and define accurate model configuration as well as model sensitivity to those parameters thus leading to reliable numerical models for impact simulations, offering also an understanding of the effect of numerical input parameters and variables on composite and sandwich laminates structural responses in terms of absorbed energy, maximum energy, maximum force and curve morphology.

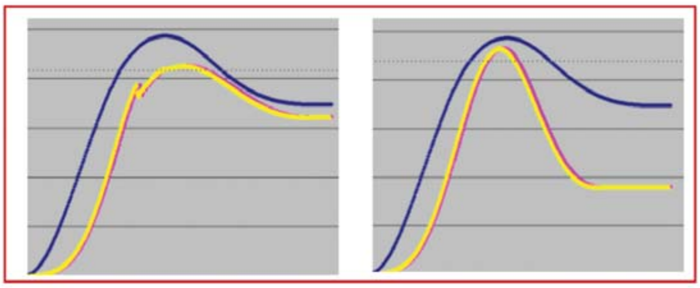
Two different types of autoclave-moulded composite laminates and four types of autoclave-moulded Kevlar – Carbon skins sandwich laminates with PVC, PMI, PU and Honeycomb cores were used.
All the impact tests were conducted
in-house according to ASTM 3763 on 110 x 110 mm square samples using a Fractovis CEAST drop tower. The transient



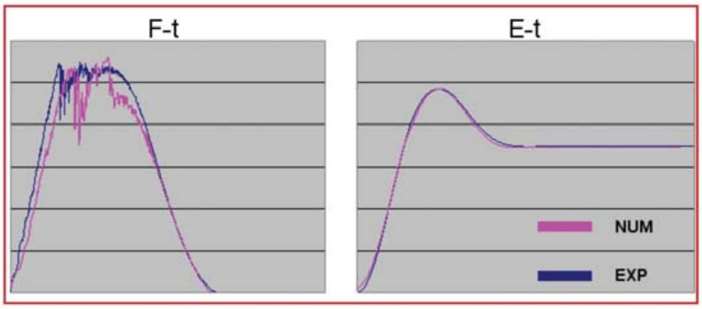
Calibration and experimental validation of LS-DYNA composite material models by multi objective optimization techniques

response of each of the laminates was recorded in terms of load, energy, velocity and deflection.
Analysed laminates were modelled by shell elements with Belytschko–Tsai formulation. A multi-layered shell was used with one integration point per layer. The different composite materials were modelled using material type 58 which implements a smooth failure surface. A shell-brick-shell model was used for modelling the sandwich configuration with 2 eight-node hexa solid elements for the core (material type 63).
Simulations of quasi-static tensile test on composite laminates were performed with LS-DYNA to evaluate how the material model could manage the coupling of stresses.

The effect of the mechanical characteristics of the materials involved and of the reduction factors over both composite and sandwich laminates structural responses was managed and investigated. Data resulting from the mechanical characterization with statistical variability ranges were used as input parameters. On the other hand, the reduction factors were set as variables in a defined range. Objectives of the optimization were the matching of all the reference parameters between points on experimental and numerical F-t and E-t curves. Two main tools were used for the multi-objective analysis: Pareto's frontier and Student's chart.



Trial and Test better solution



Virtual Prototyping approach solutions

The multi-objective analysis demonstrates a good compliance, with a delta less than 5% between numerical and experimental results for all the reference parameters and the curve morphology in case of pure composite samples whereas a delta of 6 % for the worst sandwich configuration is found.
This approach allows defining only one set of reduction factors for each material: This means that the correct way to approach the definition of material input parameters for composites in LS-DYNA is to calibrate the reduction factors via numerical drop test simulations.

Synthetically, the virtual prototyping procedure created for composite structure impact design is tested on an impact resistance approach project: PTW helmet. The procedure adopted an integrated experimental-numerical method for the calibration of LS-DYNA input parameters for material model 58 and 63, by means of the integrated platform modeFRONTIER. Material model 58 was used for modelling woven fabrics while material model 63 was used for crushable foam modelling.
In a previous project in the same area not shown here, the approach was made with a Trial and Test method: The results obtained proved that it is not possible to achieve contemporarily each target (Maximum Energy and Adsorbed Energy) without applying a real multi-objective methodology.
The obtained results provide a general indication of the quality of the procedure used for calibrating numerical input parameters needed for confident impact simulation of simple or complex composites or sandwich structures.

A design methodology has been developed to validate the numerical prediction of the energy absorption capability of a composite or sandwich laminate, through the combined use of experimental, numerical and optimization tools: Experimental tests were conducted over different types of composite laminates and sandwich laminates in order to calibrate LS-DYNA composite material model input parameters.

Stefano Magistrali
Omega Srl, Research and Innovation Centre, Tortona fraz. Rivalta Scrivia (AL) - Italy
Marco Perillo
info@enginsoft.it
EnginSoft SpA, Florence - Italy