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NUMERICAL-EXPERIMENTAL CORRELATION OF COMPOSITE LAMINATES FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

Lightweight design, structural performance and safety requirements represent the reference tasks for the development of innovative cars. For these reasons, both composites and Finite Element (FE) modelling have been widely employed in the last years. This study illustrates a numerical-experimental correlation methodology for Carbon Fibre Reinforcement Plastic (CFRP) laminates employed in a front Maserati hood. At first, an elastic-plastic material law is assessed for orthotropic shells using the Crash Survivability (CRASURV) nonlinear formulation, and a card material is compiled. A wide experimental campaign is performed according to the ASTM standards. Therefore, tensile, compression, shear, inter-laminar shear strength tests and drop weight tests are mandatory for the evaluation of the material properties and its failure modes. Finally, nonlinear forecasts of head impact on the hood are examined, and a preliminary numerical-experimental correlation is presented.

Keywords: composite material, numerical-experimental correlation, automotive chassis, FE analysis, head impact.

INTRODUCTION

In the recent years, composites have been widely used for automobile hoods manufacturing, and the evaluation of pedestrian head injury represents a recurring research topic. In (Zhang, 2008) and (Lopes, 2009 I, Lopes, 2009, II), a review of the nonlinear dynamic stability, failure and transient response of composite laminates has been presented and constitutive models of 3D panels under low-velocity impact have been investigated, respectively. In (Miscia, 2013), a genetic optimization technique has been performed on shell elements to automate the evaluation of the material properties for mono- and multi-composite laminates. A numerical-experimental correlation for CFRP hood involved in head impact tests has been preliminary illustrated.

In (Okamoto, 2003), the influence of the vehicle front shape and its "construction (rigidity) on the head contact points" has been examined. The present work investigates the propagation of the damage and the failure prediction of composite HR carbon fiber laminates. At first, an extensive experimental campaign has been accomplished to collect the stress-strain behaviour of the material loaded by both static and dynamic loads according to ASTM regulations. A numerical-experimental correlation is performed for shell elements by RADIOSS solver. The material card is based on orthotropic elastic-plastic material law, where Tsai-Wu failure criterion is adopted. Finally, nonlinear FE modelling of direct head impact on the Maserati hood is examined, and a comparison with the experimental test is presented.

RESULTS

A wide experimental campaign has been carried out and for each type of test, eight samples have been considered. The following graphs report normalized curves for confidentiality reason. The tensile experimental curves underline a linear elastic behaviour and a brittle failure mechanism, Fig. 1. shows the experimental curves that represent the average mechanical characteristics collected during the experimental campaign. In the compression and shear experimental curves an evident elastic-plastic stress-strain law appears, see Fig. 2 and Fig. 3. FE forecasts have been performed to mimic the experimental behaviour using RADIOSS solver. However, the orthotropic material law applied to composite shell elements does not differentiate the material stiffness due to a purely tensile, and by a purely compressive load for the same stacking sequence (0 or 90 degrees orientation). Therefore, an admissible balance between the tensile and the compressive Young modulus has been accepted and adopted. Then the plastic portion of the curves has been defined through the ARSM (adaptive response surface method), Fig. 1, Fig. 2 and Fig. 3 show the comparison between the numerical-experimental correlation; indeed an excellent agreement is achieved.

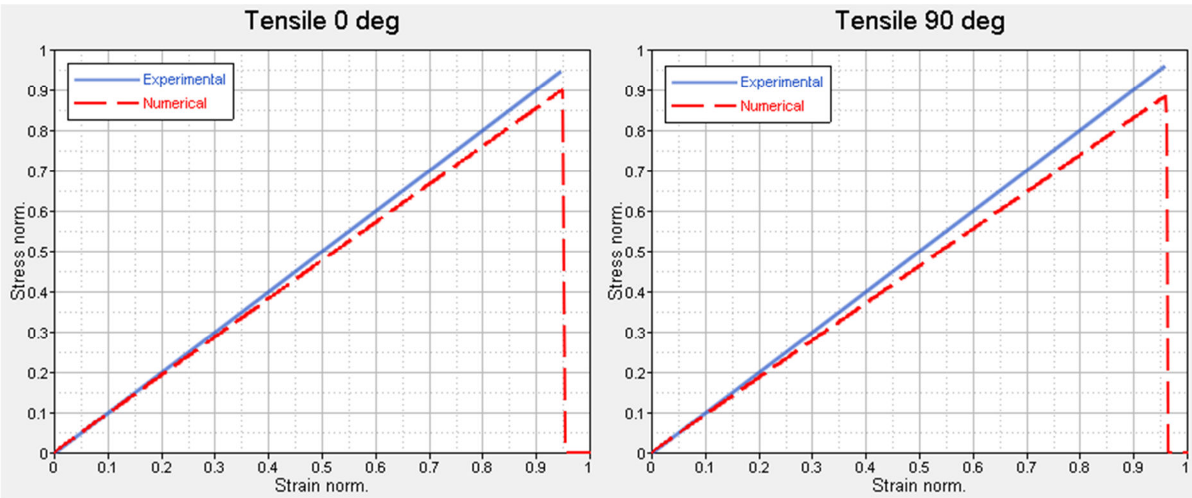

Fig. 1 - Tensile test: experimental-numerical comparison.

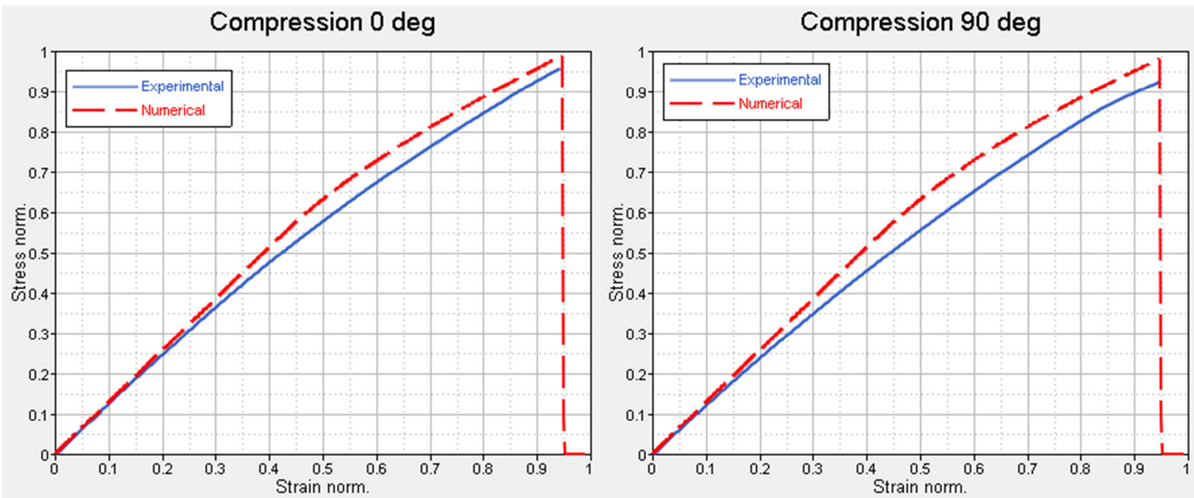

Fig. 2 - Compression test: experimental-numerical comparison.

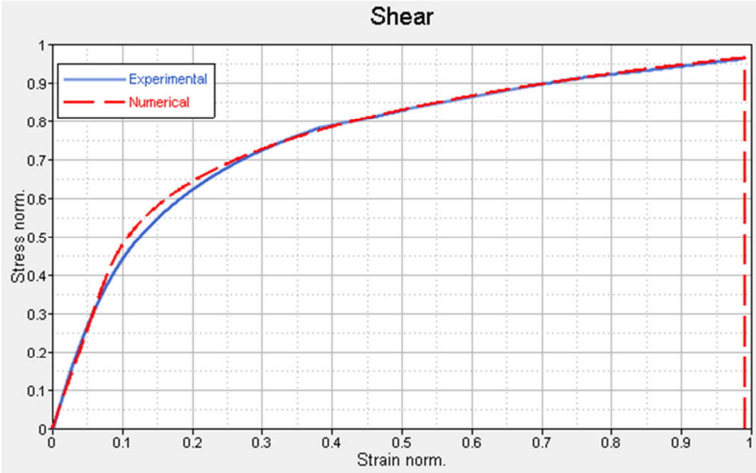

Fig. 3 - Shear test: experimental-numerical comparison.

A further correlation of drop weight test specimens has been investigated and the material card parameters that influence the out of plane behaviour have been defined by an iterative approach, about 60 parameters have been defined to compile the material card. The numerical-experimental comparison of the drop weight test is shown in Fig. 4 and Fig. 5.

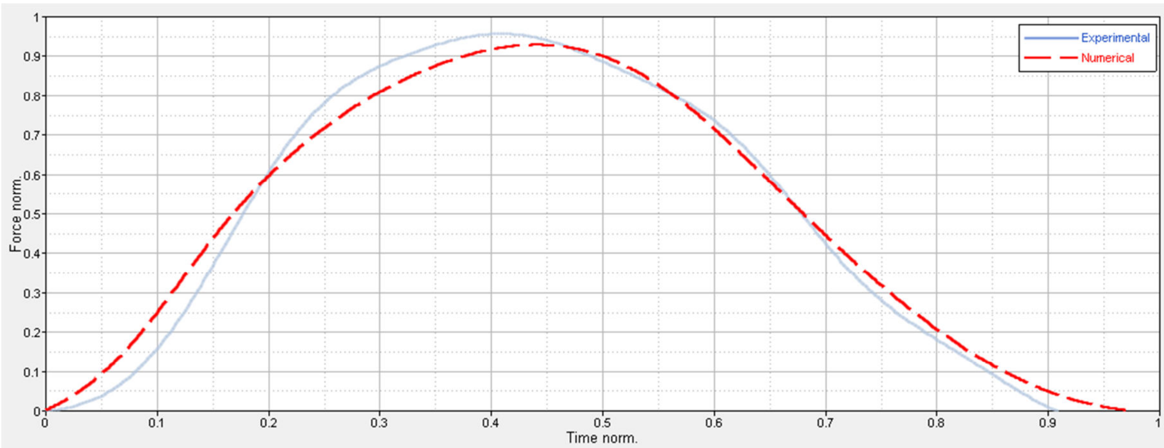

Fig. 4 - Drop weight test: force displacement experimental-numerical comparison.

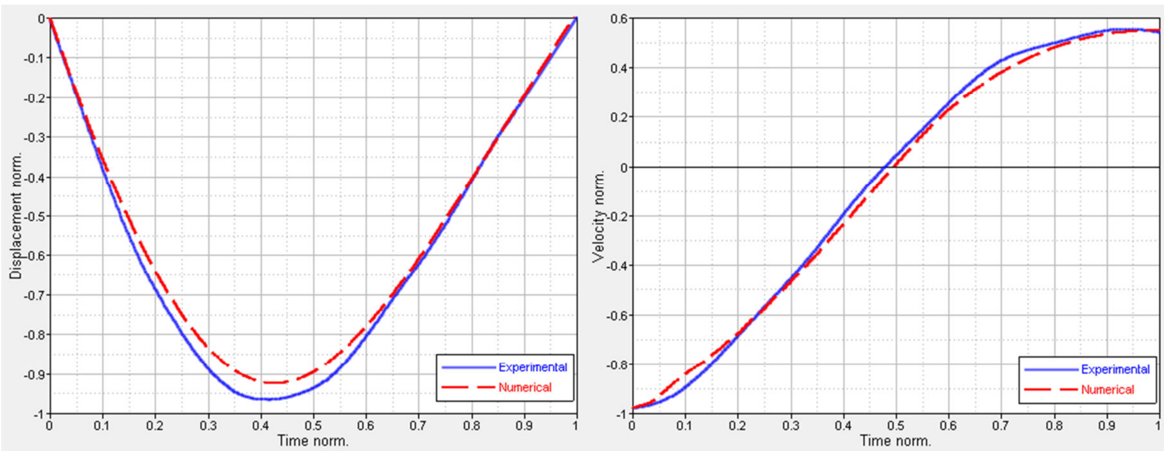

Fig. 5 - Drop weight test: time displacement and time velocity experimental-numerical comparison.

The major aim of this activity is to apply the correlated card material to a pedestrian head impact for the CFRP hood of a Maserati vehicle. Fig.6 shows the FE cut-body model that includes all parts of the car front structure, and all under bonnet components that may be involved in this case study, according to the ECE 127 Pedestrian Head Impact.

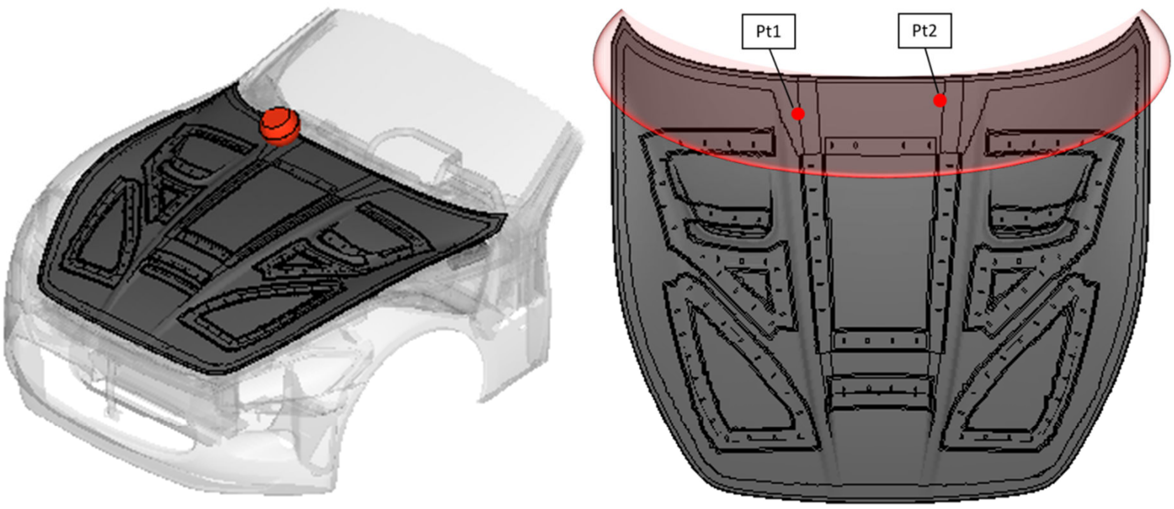

Fig. 6 - Pedestrian head impact FE model and example of monitored points on the CFRP hood during the head impact test.

The adult headform test area has been defined following the ECE 127 Pedestrian Head Impact regulation and in Fig. 6. a simplified interested zone and significant monitored points are highlighted. The position of the two significant points Pt1 and Pt2 has been decided in order to limited influence of the boundary conditions applied the hood during the experimental test. In fact the rear part of the CFRP hood was mounted on steel hinges by bolts and was support in the lateral part on the front fenders. Fig. 7 and Fig. 8 show the comparison between the numerical-experimental correlation of both the points, a good agreement has been obtained.

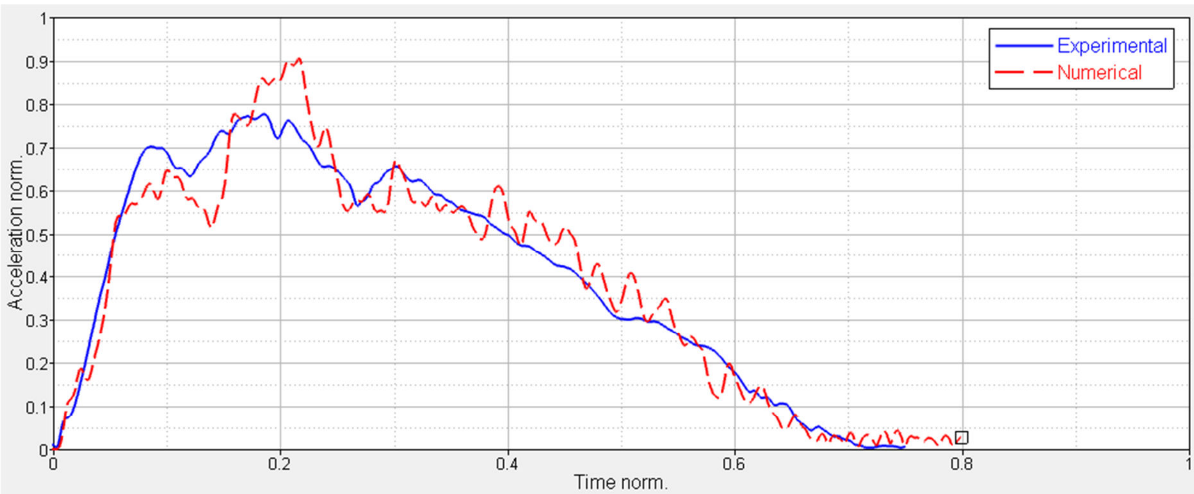

Fig. 7 - Pt1 Experimental-numerical comparison.

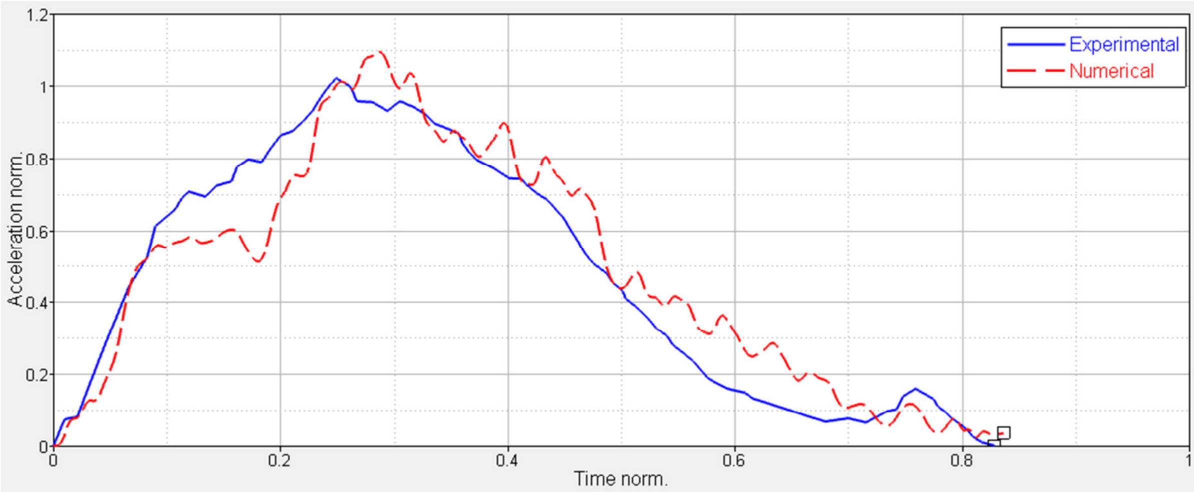

Fig. 8 - Pt2 Experimental-numerical comparison.

The Head Injury Criterion (HIC) has been calculated using the following equation:

$$HIC = \left[\frac{1}{t1 - t1}\int_{t1}^{t2} a\,dt\right]^{2.5} (t2 - t1)$$

For both the points Pt1 and Pt2 the difference between the experimental and numerical HIC value is lower than the 10 percent.

CONCLUSIONS

A methodology to generate carbon fiber material cards for nonlinear analysis has been described. Tensile, compression and shear samples have been tested in order to characterize the in plane material parameter. The drop weight test specimens was accomplished to refine the parameters that describe the out of plane behaviour of the material card. The definitive validation of the material card was performed on the pedestrian head impact for the CFRP hood. The agreement between experimental and numerical results was satisfactory and confirms the effectiveness of the methodology.

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