F2008-SC-016

CRASH ANALYSIS OF AN IMPACT ATTENUATOR FOR RACING CAR IN SANDWICH MATERIAL

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KEYWORDS – sandwich panel, crush behaviour, numerical simulation, LS-DYNA

ABSTRACT – Aluminium sandwich construction has been recognized as a promising concept for structural design of lightweight transportation systems. The aim of the present study is to investigate, experimentally and numerically, the energy absorbing capabilities of a thin-walled crash-box, made of aluminium sandwich material, for a racing car. The crash-tests were performed for a frontal impact at the velocity of 12 m/s; during the impact were measured the load-shortening diagram, the deceleration and the energy absorbed by the structure. A finite element model is then developed using the non-linear, explicit dynamic code LS-DYNA. To set up the numerical model, a series of strength tests were carried out on aluminium sandwich panel specimen to determine the material properties.

INTRODUCTION

For design and construction of lightweight transportation systems such as aircraft, high-speed trains, fast ferries and automobile, structural weight saving is one of the major considerations. To meet this requirement, sandwich construction is frequently used instead of increasing material thickness. This type of construction consists of two thin facing layers separated by a core material. Potential materials for sandwich facings are aluminium alloys or composites depending on the specific mission requirement. Several types of core shapes and core material have been applied to the construction of sandwich structures. Among them, the honeycomb core that consists of very thin foils in the form of hexagonal cells perpendicular to the facings is the most popular.

A sandwich construction provides excellent structural efficiency, i.e., with high ratio of strength to weight. Other advantages offered by sandwich construction are elimination of welding, superior insulating qualities and design versatility. Even if the concept of sandwich construction is not very new, it has primarily been adopted for non-strength part of structures in the last decade. This is because there are a variety of problem areas to be overcome when the sandwich construction is applied to design of dynamically loaded structures.

The aim of the present study is to investigate the dynamic behaviour of a thin-walled crash-box for a racing car, built by Picchio S.p.A. and made of aluminium sandwich material (Fig.1).

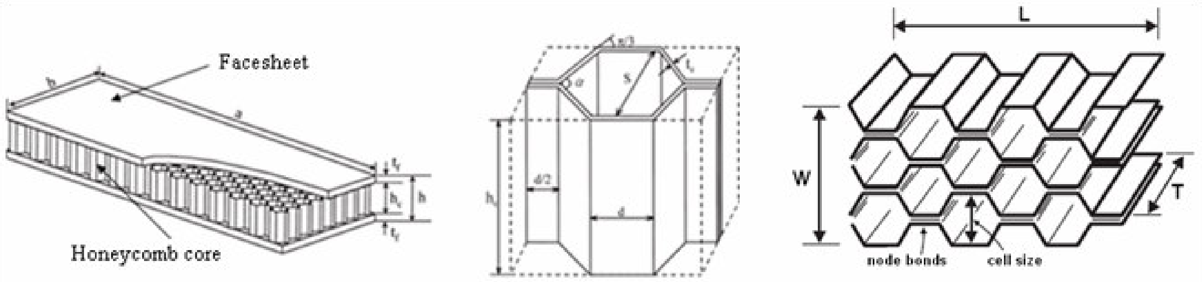

Figure 1: Honeycomb sandwich structure.

In order to analyse its energy absorbing capabilities numerical simulations, with the explicit finite element code LS-DYNA (1), were used in addition to dynamic testing.

Different approaches for modelling sandwich structures by the FE method exist (2-4), which differ in modelling, computational cost and accuracy of the results and their adoption depends on the specific model size and loading case. A detailed representation of the hexagonal cells with shell elements (Fig. 2b) predicts well the cell wall deformation for impact simulations, but it is unsuitable for large scale models due to the computational cost and time required. A possible simplification may consist in representing the cellular core as an homogeneous continuum using the honeycomb structure's effective orthotropic material properties (Fig. 2c).

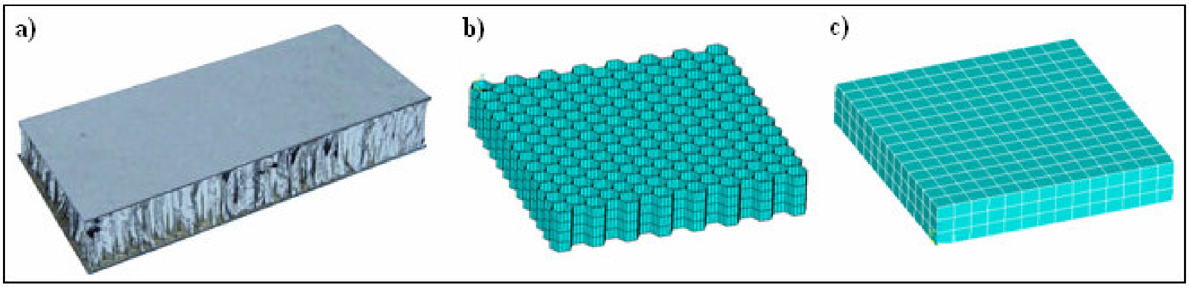

Figure 2: Models for cellular core: a) real, b) detailed cell wall modelling, c) modelling with solid elements.

Since the main goal of the presently discussed dynamic simulation of the crash-box is the consideration of the most part of the failure modes, a three-dimensional modelling approach with solid elements for the core and shell elements for the face sheets was adopted.

STRENGTH TESTS OF ALUMINIUM HONEYCOMB SANDWICH PANELS

Theoretically, a variety of possible failure modes for aluminium honeycomb sandwich panels can be considered when they are used as strength members in the dynamically loaded structure. They include elasto-plastic large deflection due to bending, buckling/collapse in axial compression, folding of honeycomb cores under lateral impact pressure and debonding between the center core and facing plates.

To investigate the structural failure characteristics mentioned above, three types of experiments, namely out-of-plane compression, three point bending tests and buckling tests under (in-plane) axial compression are undertaken in the present study using an aluminium honeycomb-cored sandwich panel specimen.

All test specimens consist of two materials, namely A5052–H111 for honeycomb cores and A6082–T6 for facing skins. Table 1 shows the mechanical properties of the aluminium honeycomb core which were provided by the core manufacturer. Table 2 shows, instead, mechanical properties for the facing plate material A6082–T6, which were obtained from tensile tests.

Core density (kg/m^3)	68.8
Yield stress (MPa)	193
Elongation (%)	12
Compressive modulus (MPa)	965
Compressive strength (MPa)	2.5
Shear strength, L (MPa)	2
Shear strength, W (MPa)	1.2
Shear modulus, L (MPa)	455
Shear modulus, W (MPa)	205

Table 1: Mechanical properties of aluminium honeycomb core material A5052-H111.

Young’s modulus (MPa)	69000
Yield strength (MPa)	250
Tensile strength (MPa)	290
Elongation at rupture (%)	10

Table 2: Mechanical properties of facing plate material A6082-T6.

Several honeycomb specimens cut from the sheets analyzed were crushed between two rigid platens (Fig.3) under displacement control in a standard testing machine. A computer-operated data acquisition system was used to monitor the load and displacement during the crushing test (Fig.4).

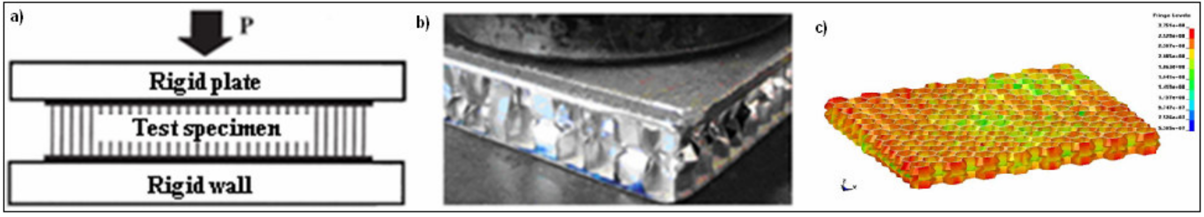

Figure 3: Compression in T-direction: a) scheme, b) experiment, c) simulation.

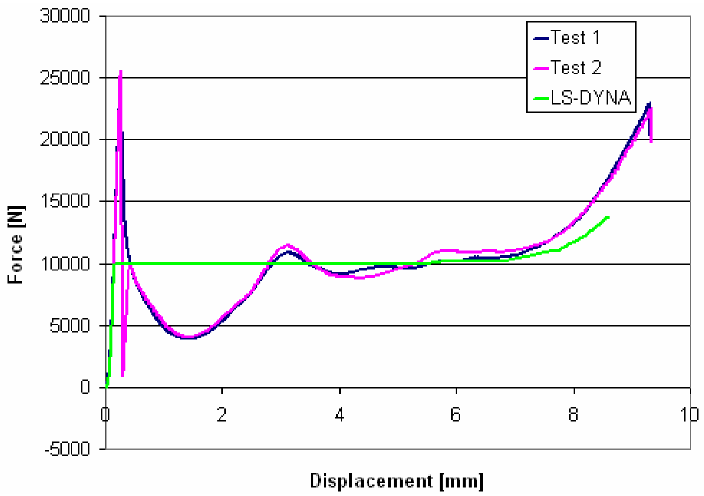

Figure 4: Load versus deformation curve.

The sharp initial peak appears immediately after the tool contact. In the quasi-static experiment, the compressive stress is almost constant during compression and the crush strength determined is about 2 MPa. On the other hand, in the impact test, it increases with the hammer travel. This is attributed to the increase of the air pressure enclosed in the honeycomb during compression and has been investigated by many researchers (5). Of course, the leak of air through the gap between the honeycomb and the compressing tool becomes remarkable as the pressure increases. Finally, the curve shows the excessive compressive stress due to the densification of the honeycomb.

For the compression in T-direction models of the core structure with Belytschko-Tsay shell elements were used. The influence of mesh size on the structure’s effective properties was also investigated in the simulations; the mesh size, in fact, influences the ability of representing cell wall buckling in an accurate manner.

After the parameters of the cell wall were determined and validated against experimental data of the core manufacturer, material testing simulations were performed for in-plane compression and shear in all other material directions. For the orthotropic material model, in fact, stress-strain curves in compression and shear for all directions are necessary. But since test series on honeycomb material normally require a rather large amount of time and cost associated with specimens preparation and testing devices setting up, an alternative way of determining these nonlinear effective mechanical properties was combining a minimum of experimental data with numerical simulations.

After developing the material models for honeycomb core, two other experiments in sandwich components were performed in order to verify the reliability of the material model. The three point bending test was carried out to investigate the characteristics of bending behaviour of sandwich panels and also to analyze the shear effects of honeycomb core. Edgewise compression tests were used, instead, for the evaluation of sandwich failure modes under in-plane compression. The tests were conduced in two different directions (L and W), but no large difference in strength between them was detected. The sandwich panels failed in a shear crimping or in a face wrinkling mode; both failure modes could be represented rather satisfactorily in the corresponding LS-DYNA simulations (Fig.5).

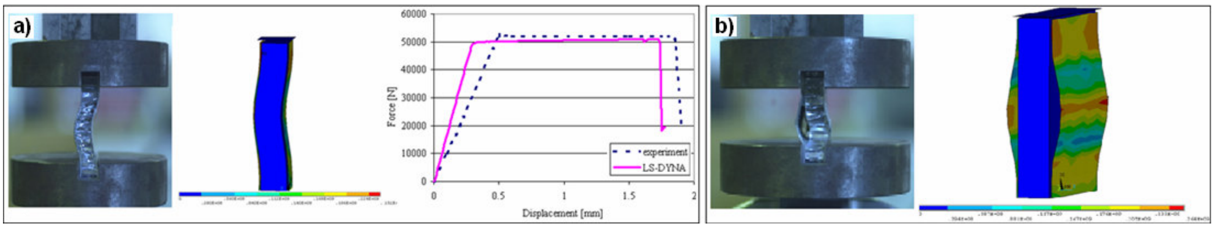

Figure 5: a) Shear crimping failure, b) face wrinkling failure.

DYNAMC SIMULATION OF A CRASH-BOX FOR RACING CAR

In 1980, the FIA introduced the impact test on the crash-box of a CN2 prototype. This test is of fundamental importance as the first element that goes in contact in case of a frontal impact is the crash-box. If it is not able to absorb correctly the impact, it can cause serious injuries to the pilot. During the crash-test the crash-box and the front part of the survival cell are subjected to an impact against a solid and vertical barrier at the velocity of 12 m/s. During the test average deceleration of the system must not exceed 25 g and the total deformation must be limited to the impact attenuator.

In the framework of the presently discussed research activity, actual prototype manufacturing and testing of each configuration would be too expensive in cost and time. For these reasons, numerical FE models have been developed to predict the structural behaviour under dynamic loads. The total system was simulated by the right combination of a crash-box and a striking mass that impact a barrier (Fig.6).

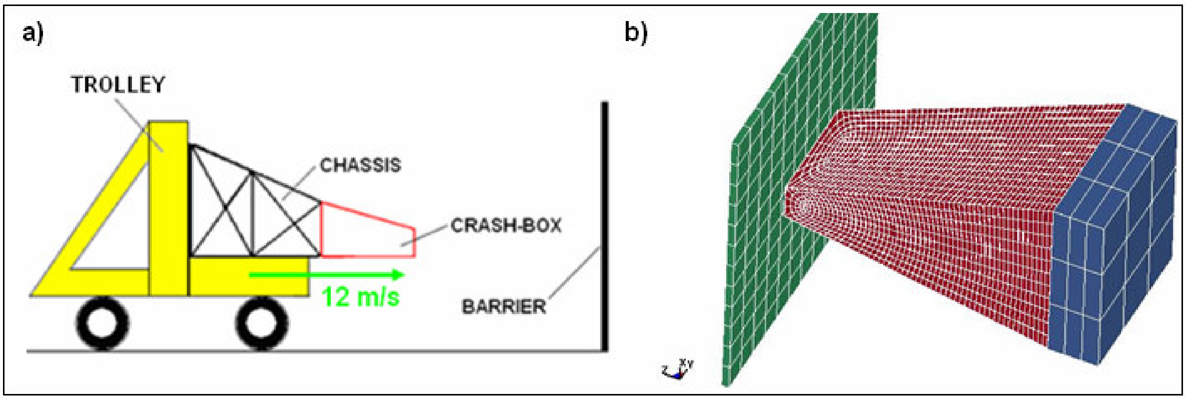

Figure 6: Total system: a) scheme, b) numerical model.

A three-dimensional modelling approach of the sandwich crash-box with solid elements for the core and shell elements for the face sheets was adopted (Fig.7). For the aluminium external sheets and for honeycomb core material #24 (*MAT_PIECEWISE_LINEAR_PLASTICITY) and #26 (*MAT_HONEYCOMB) of the LS-DYNA material model library were used, respectively. Between the core and the sheets a 'tiebreak' contact was used in order to simulate the adhesive: for this interface additional inputs, such as normal and shear failure stresses, are necessary.

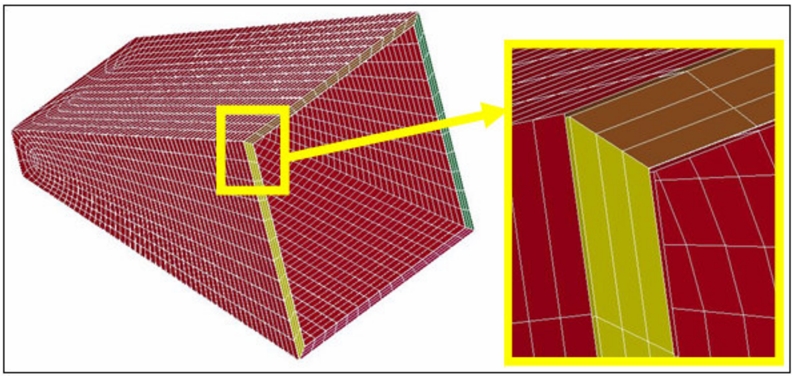

Figure 7: Crash-box.

The barrier and the moving mass were simulated with solid element and were also considered as rigid bodies. The interface type 'node-to-surface' is used for the contact between the barrier and the crash-box during the impact. Moreover a self-contact of the inner and the outer surfaces of the crash-box was imposed. The boundary condition refers to the barrier and to the moving mass; the first is constrained in all degrees of freedom, while for the second displacements along the forward direction only were permitted with a constant initial velocity of 12 m/s.

After several simulations has been shown the importance to model rivets accurately well, because they influence the final deformation significantly.

The LS-DYNA simulations results showed good agreement with the experimental data (Fig.8), recorded during some preliminary crash-tests, in terms of displacement, velocity (Fig.9) and deceleration (Fig.10).

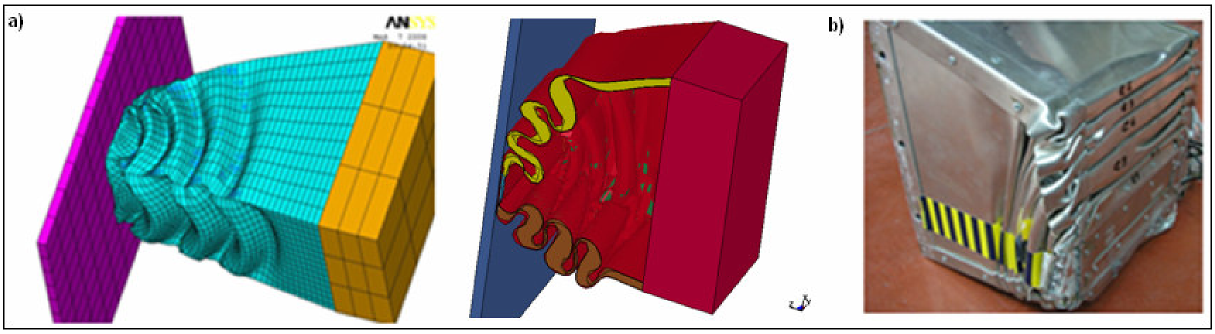

Figure 8: a) Partial numerical deformation, b) total real deformation.

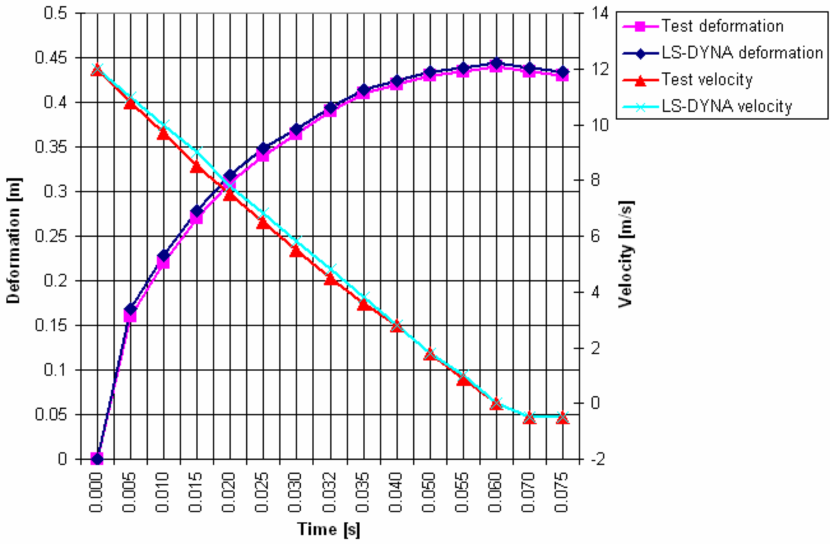

Figure 9: Deformation and velocity versus time.

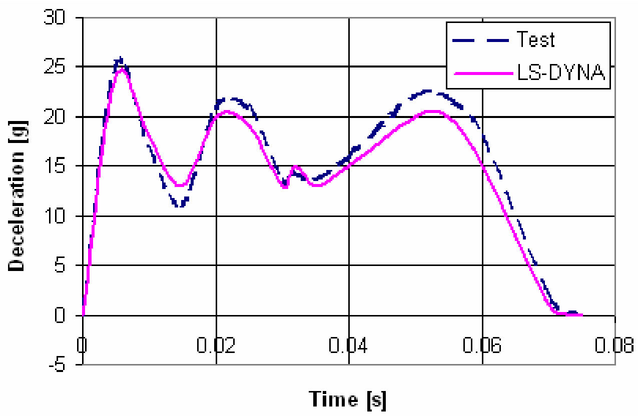

Figure 10: Deceleration versus time.

CONCLUSION

The present paper describes an experimental and numerical investigation of an energy absorber for a CN2 prototype. The crash-tests are performed measuring the load-shortening diagram, the deceleration and the energy absorbed by the structure. A finite element model is then developed using the non-linear explicit dynamic code LS-DYNA. To set up the numerical model, aluminium sandwich panels crushing testing are conducted to determine the material failure modes and to characterise them with LS-DYNA.

REFERENCES

(1) LS-DYNA, Keyword User's Manual, Version 970, LSTC, 2003.
(2) Chamis, C.C., Aiello, R.A., Murthy, P.L.N., "Fiber composite sandwich thermostructural behaviour: computational simulation", Journal of Composite Technology & Research, 10, pp. 93-99, 1988.
(3) Aktay, L., Johnson, A.F., Holzapfel, M., "Prediction of impact damage on sandwich composite panels", Computational Materials Science, 32, pp. 252-260, 2005.
(4) Noor, A.K., Burton, W.S., Bert, C.W., "Computational models for sandwich panels and shells", Applied Mechanics Reviews, 49, pp. 155-199, 1996.
(5) Wu, E., Jiang, W.-S., "Axial crush of metallic honeycombs", International Journal of Impact Engineering, 19, pp. 439-456, 1996.