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# Non-Linear Damping Behavior of PVC Foam Core Sandwich Composite Panels in Low-Velocity Impact

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**Abstract**

In this study A numerical modeling of the nonlinear damping behavior in axisymmetrical conditions was performed using the ABAQUS finite element computer code. Damping is a useful parameter for controlling vibration in moving structures. Due to their high stiffness and strength to weight ratios, composite sandwich structures have proven their usefulness in a large number of applications in various technical fields, especially in aeronautics, automotive and civil engineering. The plastic response of the foam core is modeled by the *CRUSHABLE FOAM and the *CRUSHABLE FOAM HARDENING option of the ABAQUS code. The present work should be considered as a step towards developing a more sophisticated numerical model capable of describing nonlinear damping as well as indentation mechanical behavior of sandwich structures.
Keywords: Nonlinear behavior; Damping; Plastic response; Sandwich composite structure; Indentation; Finite element analysis; plastic response.

## 1. Introduction

The problem of dissipating energy in structures so as to reduce the amplitudes of the vibrations is an important feature in mechanical design. Generally, the damping in metal structures is low, which results in high amplitudes of the vibrations. For fibre reinforced composite materials, damping is higher and it depends on the constitution of the materials. The function of the face sheets is to the main concerns in the application of sandwich composite structures is the fact that their load carrying ability may be significantly reduced by the presence of a carry bending and in-plane forces, while the role of the core is to keep together the face sheets and to carry transverse shear loads. The combination between a thick core and thin stiff face sheets allows exceptional lightweight advantages. One of local damage (delamination) between the core and the face. in order to identify the PVC foam behavior and numerical simulation review papers [1,2]. The initial works on the damping analysis and finite element were reviewed extensively in review papers [3,4,5]. when the foams undergo large deformations, the core behavior is non-linear (it crushes) and this leads to formation of a residual dent after unloading. Thus, it is necessary to introduce this non-linearity in the analysis of the damping response of sandwich composite structures. The purpose of this paper is to show how the transverse shear effects combined with a finite element analysis allows us to describe the damping characteristics and the dynamic response of structures constituted of laminates, laminates with sandwich materials.

## Materials

The present study concerns sandwich composite beams fabricated with Divinycell H100 foam core with a thickness of 40 mm and 1.5 mm thick E-glass fiber face sheets. The laminate materials are constituted of E-glass fibres in an epoxy matrix. The nominal density of the foam was 100 kg/m$^3$. Only quasi-isotropic and symmetric lay-up $(0°/90°,\pm45°)_{2s}$ was chosen. This configuration avoided introduction of the plies orientation as a further parameter in computer simulations Basic mechanical properties of PVC foam core and face sheet laminates are given in Table 1.

Table 1. Mechanical properties of sandwich constituents as used in the finite element modeling

| | $E_{xx}$(Gpa) | $E_{yy}$(Gpa) | $E_{zz}$(Gpa) | $G_{xy}$(Gpa) | $G_{yz}$(Gpa) | $G_{zx}$(Gpa) | $\upsilon_{xy}$ | $\upsilon_{yz}$ | $\upsilon_{xz}$ |
|---|---|---|---|---|---|---|---|---|---|
| Core | 0.35 | 0.35 | 0.35 | 0.035 | 0.035 | 0.035 | 0.3 | 0.3 | 0.3 |
| Face | 20.3 | 4.48 | 20.3 | 2.5 | 2.5 | 8.5 | 0.05 | 0.15 | 0.15 |

## 2. Finite element Model

It is known that the plastic response of cellular materials (foams) differs significantly from that of the fully dense materials owing to compaction of foams.

Due to the plastic compressibility of foams, the classical plasticity constitutive models, based on the assumption for plastic incompressibility, are not valid. In view of the above mentioned, we decided to model the Damping behavior of PVC foam core sandwich panels using the finite element package ABAQUS, version 6.5. It should be noted that usually the latest developments in the field of foam plasticity constitutive modeling are promptly included in the ABAQUS software.

**2.1. Modelling of sandwich composite panels**

sheets The aim of finite element modeling was to perform reliable simulations of the quasi-static response of sandwich composite panels in order of further understand the failure modes caused by a local indentation An axisymmetrical idealization was applied for the core, the face sheets and the indentor Four-nodded axisymmetric (CAX4) finite elements were used to discrete the sandwich core and the composite face sheets. The mesh consisted of 1000 finite elements with 25 elements through the thickness of the core, 2 elements through the thickness of each face and 20 elements divisions along the length of the sandwich panel. The nodes on the vertical axis of symmetry were locked in horizontal direction. The indentor was modeled as a rigid sphere using a rigid body option in the ABAQUS program. The indentation load was applied through a steel spherical indentor (25 mm in diameter) as shown in Fig.1. For the impact analysis the speed at the indentor is 4 mm/mint. All degrees of freedom of the indentor were constrained, except the vertical translation. In order to impose the load, the prescribed vertical displacement conditions were applied to the indentor. The contact interaction between the upper face sheet of the panel and the indentor was modeled by the contact surfaces provided by the ABAQUS package. displays the adopted finite element model (mesh and boundary conditions) of the system ‘‘indentor sandwich panel’’. The elastic part of the response of the core was defined by the *ELASTIC option with the parameters: Young’s modulus E =350 Mpa , and Poisson’s ratio $\upsilon$=0.3 The load applied to indentor is 6 KN. The plastic part of the response of the core material was modeled using the CRUSHABLE FOAM and the CRUSHABLE FOAM HARDENING options in the ABAQUS software. The geometrical nonlinearity was taken into account by using the NLGEOM option. The hardening behavior was defined in terms of uniaxial compression yield stress versus corresponding logarithmic plastic strain Fig.2. shows the stress–strain curve, obtained from the test.

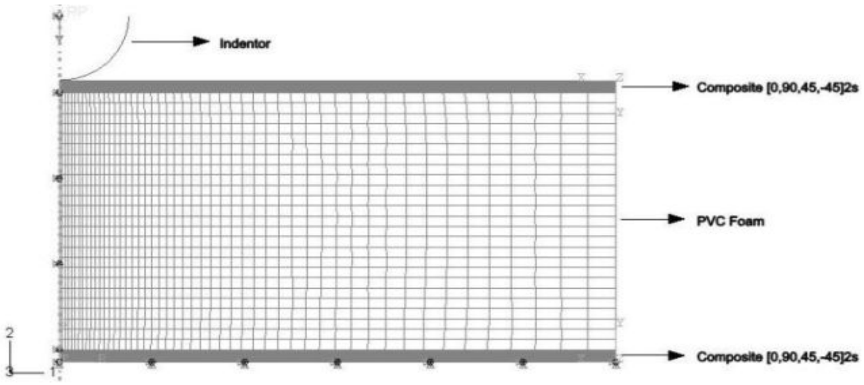


Fig. 1. Axisymmetrical finite element model of a sandwich panel indented by a spherical indentor.

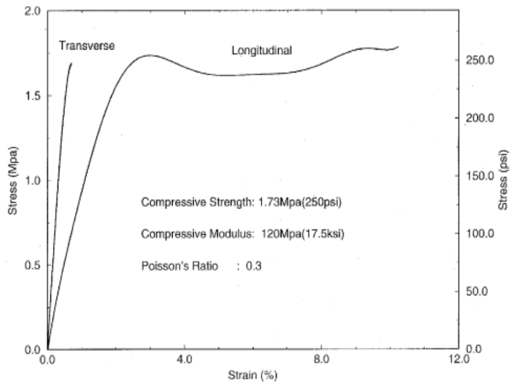


Fig. 2. stress–strain curves for Divinicell H100 Foam core under uniaxial compression.

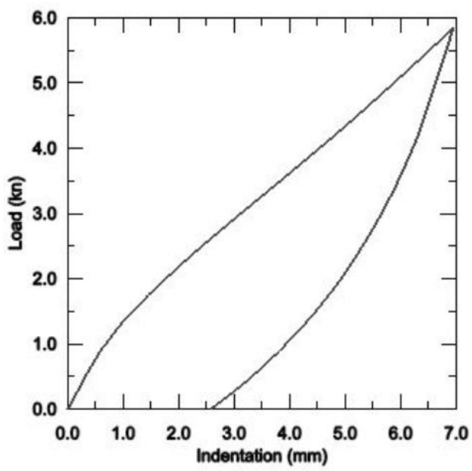


Fig. 3. Load-indentation curves deduced from the finite element modeling**.**

Along the curve, characteristic points were selected (in terms of nominal stresses and strains) and transformed into true (Cauchy) stresses and logarithmic plastic strains which were used as input data in the card CRUSHABLE FOAM HARDENING. A typical load–indentation curve for composite panel specimens is shown in Fig. 3.Due to the elastic-plastic behavior of the foam core the load–indentation curves have a generally non-linear shape that was obtained from the ABAQUS modeling.The load–deflection response of the beam specimen at unloading phase has a less pronounced non-linear character, compared to the loading (indentation) phase Fig. 3.

## 2.2. Damping analysis of PVC foam core sandwich panels

Constrained–layer damping has been widely used for the suppression of resonant vibrations in structural components. In many of these applications an optimised damping design is a practical requirement, as it is often necessary to provide an effective vibration reduction in the face of one or more design constraints. The literature contains many damping studies pertaining to full coverage of beams and plates with a uniformly distributed constrained layer. However, a much smaller number of studies look into partial coverage, in which the spatial distribution of the damping patches is as important as the thicknesses and material properties of the layers. Among these, Mantena et al. [6] and Marcelin et al. [7] investigated partial coverage of beams. In the case of studies on shells completely covered with the treatment, many researchers have investigated the variation of natural frequencies and modal loss factors and damping for different geometric and material properties, and for various boundary conditions, e.g, Abdolhosein Fereidoon, I.W. Jones [8,9], Markuš [10], Alam and Asnani [11]. Modelling can be applied to evaluate the damping properties of structures constituted of laminates. Fig.4 shows the evolution of the plastic zone in the foam core deduced from the modeling procedure. At small deflections of the face sheet, the plastic zone is first developed in radial direction.When the ability of the face sheet to distribute the load in radial direction is exceeded, the plastic zone begins to grow down in the core. Fig.5 reports the evolution of the displacement field deduced from the computer simulations. (Fig .6) shows the distribution of the vertical strains $\varepsilon_{22}$ which corresponds to the maximum indentation load deduced from the numerical solution. Fig. 7 shows the shapes of the first six modes deduced from finite element analysis. The results obtainded in Table 2 show the frequency response of the free natural modes of the structure deduced from finite element analysis. Fig.8 shows Maximum damping obtained for composite sandwich panel with PVC foam core. Fig.9 shows strain energy-time obtained from the finite element modeling.

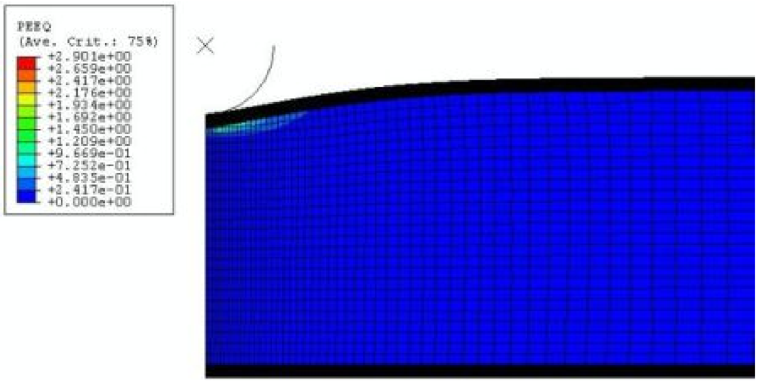


Fig. 4. Predicted contours of the volumetric compacting plastic strain in the foam core of a sandwich at indentation of 7 mm.

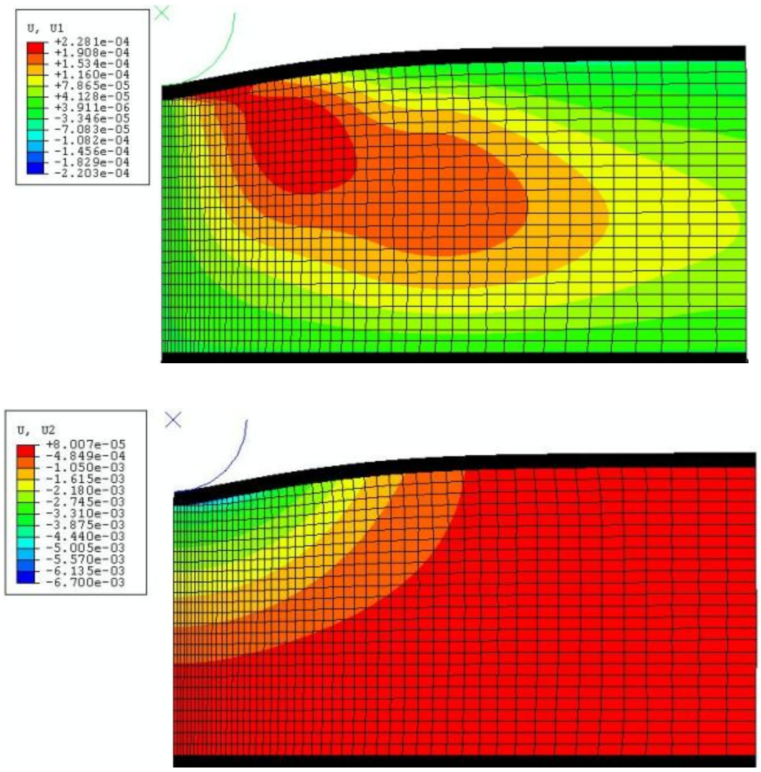


Fig. 5. Evolution of the displacement field deduced from the simulations at indentation of 7 mm.

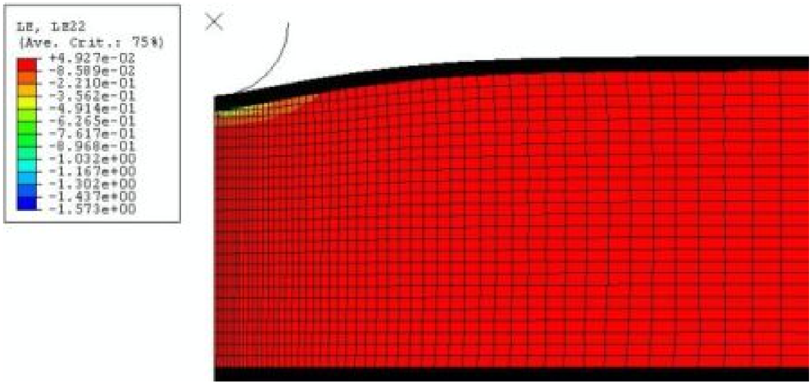


Fig. 6. Distribution of the vertical strain $\varepsilon_{22}$ corresponding to an indentation of 7 mm obtained in the finite element analysis.

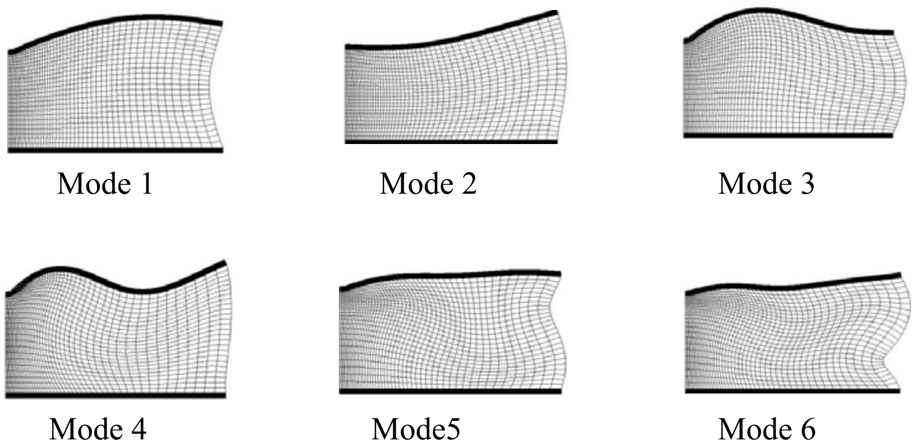


Fig.7. Examples of the shapes of the vibration modes of the composite sandwich panels.

Table 2. The frequency responses of composite sandwich panel obtained in the finite element analysis.

| Mode | Frequency(HZ) | Mode | Frequency(HZ) |
|---|---|---|---|
| Mode 1 | 3151.7 | Mode 6 | 6816.4 |
| Mode 2 | 3602.9 | Mode 7 | 7542.5 |
| Mode 3 | 4802.8 | Mode 8 | 8057.5 |
| Mode 4 | 5714.3 | Mode 9 | 8575.4 |
| Mode 5 | 6482.2 | Mode 10 | 8908.5 |

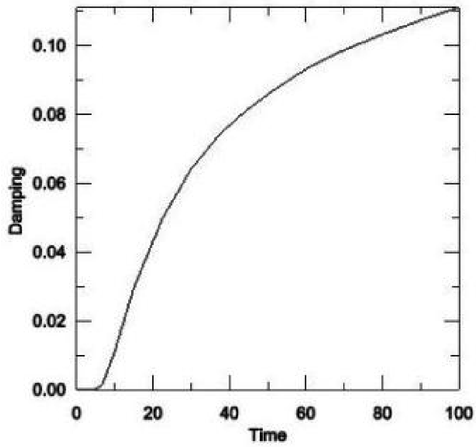


Fig. 8. Damping obtained for composite sandwich panel with PVC foam core.

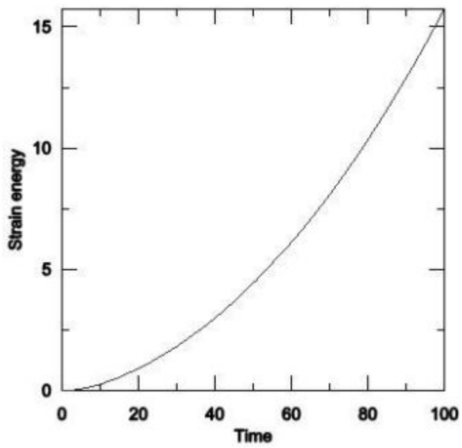


Fig.9. Strain energy-time obtained from the finite element modeling.

## 3. Conclusion

The object of the work, presented in this paper, was to develop a 2D finite element modeling procedure for analyzing the non-linear damping behavior of foam core sandwich composite beams. For this purpose the ABAQUS finite element package was used. The core was modeled as an elastic–plastic material with hardening. The large deformations induced in the case of localized loading also were taken into account in the modeling. The face sheets were assumed linear-elastic and quasi-isotropic. The indentor was modeled as a rigid cylinder. All degrees of freedom of the indentor were constrained, except translation in vertical direction (normal to the upper face sheet plane). A finite element model was developed capable of describing both loading and frequency steps. For this purpose, the ABAQUS commercial software was used. The strategy, outlined in the present article, can also be used for analysis of damping mechanical behavior of sandwich panels.

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