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ANALYSIS OF SANDWICH BEAMS WITH HOMOGENEOUS OR GRADED CORES UNDER FLEXURAL LOADING

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1. INTRODUCTION

Sandwich structures have been in the center of interest for several industries, such as the automotive, aerospace or marine ones during the last decades. Characteristics like their increased stiffness to weight ratio have made them eligible for a number of applications as substitutes of traditional structures, like metallic ones. Different kinds of sandwich structures exist, depending on the materials used to construct their skin panels and cores, the two components that they consist of. Common materials for the skin panels are metal alloys, carbon fiber reinforced polymers (CFRPs) or glass fiber reinforced polymers (GFRPs). On the other hand, a variety of materials is also used for the core construction, such as honeycombs, woods (e.g. Balsa core), polymers or foams [1-4]. An aspect of sandwich structures that has been attending interest is the effect that the technique of "gradation" has in their mechanical behavior under a variety of loads they are subjected to. This concept of gradation appeared in the work presented by Kaboglu et. al. [5] in the 20th International Conference on Composite Materials in Copenhagen. Their primary aim was to study the effect of changing the skin-core configuration on the mechanical response of the sandwich structures tested, which consisted of GFRP skin panels and PVC foam cores. More specifically, their interest focused on the sandwich structure behavior when different core configurations were used in three and four-point bending experiments. In the study of Kaboglu et al. [5] four core configurations were used : a) Core with a single layer of uniform density b) Core with three uniform density layers c) Graded core with three distinct layers in a high-low-high configuration d) Graded core with three distinct layers in a low-high-low configuration. For reasons of comparison, the mean densities of all the configurations were kept approximately the same. Using the technique of Digital Image Correlation (DIC), critical regions were identified and the effect of the core configuration was highlighted. Their results showed that the uniformity of core leads to higher load-bearing capabilities, but the graded core configurations provides a smoother failure process in regard with the uniform case. The importance of this result lays in the usefulness of the concept of gradation to ensure the achievement of a failure mode that is preferable according to the application where the sandwich structure is used.

2. PRESENT STUDY

Intention of this study is to perform a thorough investigation of the capabilities of the commercial Finite Element explicit code LS-DYNA [6], in the prediction of the mechanical response of the sandwich structures [7]. The challenging part of this investigation is the effort to combine the highly nonlinear behavior of the PVC foam cores in fundamental experiments such as uniaxial tension, uniaxial compression or shear, with the solution capabilities provided by LS-DYNA©. The lack of direct experimental results on the materials comprising the sandwich structures leads to another challenge. As the material models provided by the software need a non-negligible amount of experimental data, our effort is also focused on predicting experimental results based on engineering assumptions, analytical calculations, research conducted by others or data provided by the manufacturers in the literature. Furthermore, due to the fact that the experimental configuration is reproduced in the LS-DYNA© interface in a 3D manner, numerical aspects of the problem, such as the correct definition of the contacts between the different materials, add more interest to the whole project. In this study the behavior of the sandwich structures is being investigated under three-point bending loading.

3. GEOMETRIC FEATURES AND MATERIALS

Skin Panels

The GFRP skin panels of the sandwich structures comprise of Gurit XE603 +/-45 biaxial E-glass fiber reinforcement fabrics and a mixture of Prime 20 LV epoxy resin and slow hardener. They are stacked in a [0/90]/[-45/45]/[90/0] lay-up [5].

Foam Core

The PVC foam core used is AIREX C.70, a closed cell, cross-linked PVC foam. The specific products that are used are the C70.55, C70.75 and C70.90, which are designated as "low density" (60 kg/m^3), "middle density" (80 kg/m^3) and "high density" (100 kg/m^3) foam core for the present study. Properties for these cores were directly obtained from the manufacturer Airex Baltek Banova [5].

Core Configurations

The core configurations under consideration are presented in Table. 1.

Table 1: The core configurations examined in the study.

<table>
<tr><th>Configuration</th><th>[80]</th><th>[80/80/80]</th><th>[60/100/60]</th><th>[100/60/100]</th></tr>
<tr><td rowspan="5">Layup</td><td colspan="4">6 layers of glass fiber ([0/90/-45/45/90/0] layup with epoxy matrix</td></tr>
<tr><td rowspan="3">80 kg/m^3 foam
(15 mm thick)</td><td>80 kg/m^3 foam
(5 mm thick)</td><td>60 kg/m^3 foam
(5 mm thick)</td><td>100 kg/m^3 foam
(5 mm thick)</td></tr>
<tr><td>80 kg/m^3 foam
(5 mm thick)</td><td>100 kg/m^3 foam
(5 mm thick)</td><td>60 kg/m^3 foam
(5 mm thick)</td></tr>
<tr><td>80 kg/m^3 foam
(5 mm thick)</td><td>60 kg/m^3 foam
(5 mm thick)</td><td>100 kg/m^3 foam
(5 mm thick)</td></tr>
<tr><td colspan="4">6 layers of glass fiber ([0/90/-45/45/90/0] layup with epoxy matrix</td></tr>
<tr><td>Average core density (kg/m^3)</td><td>80</td><td>80</td><td>73</td><td>87</td></tr>
</table>

Three-point Bending Configuration

The geometric features of the specimens used for three-point bending experiments are presented in Table 2.

Table 2: Geometric features of the three-point bending experiments.

Specimen dimensions (L x W x T) (mm x mm x mm)	300 x 75 x 18
Span of cylindrical supports (mm)	200
Diameter of cylindrical supports and indentor (mm)	12
Velocity of the indentor (mm/min)	6

4. FINITE ELEMENT MODELING

Material Models

The material models examined in the LS-DYNA code [6] for their applicability are the following ones:

- MAT_COMPOSITE_DAMAGE (MAT 22) for the GFRP skin panels, which is a relatively simply defined material model for composite materials. Properties such as elastic moduli and fracture stresses in tension, compression and shear are required for its definition.
- MAT_HONEYCOMB (MAT 26) for the PVC foam core, which is a material model applying to honeycombs or anisotropic foams, like the C.70 ones. Its consideration of a zero Poisson ratio for the material is under investigation, as experiments show an elastic Poisson ratio >0.3 for the foams under investigation. Values of the elastic moduli are required for its definition, as well as stress-strain curves of uniaxial compression and shear experiments.
- MAT_TRANSVERSELY_ISOTROPIC_CRUSHABLE_FOAM (MAT 142) for the PVC foam core, which is a material model applying to anisotropic foams as an alternative to the honeycomb model mentioned above. The same input are required for its definition, and their only difference lies in the way the foam yield criterion is applied.
- MAT_RIGID (MAT 20) for the indentor and supports, which is the standard choice for parts that are practically non-deformable in the simulation.

It is noted that a third material model for the PVC foam core was examined, the MAT_CRUSHABLE_FOAM, which is an isotropic foam model, defined by elastic moduli and a single uniaxial compression stress-strain curve. This material model failed to sufficiently simulate the sandwich structures bending response, probably due to the fact of the important role that the shear stresses which play in these cases.

Element Type

The elements used are 3D hexahedral solids with reduced integration for computational efficiency for both the skin panels and the core. In the LS-DYNA environment [6], this option is characterized as “constant stress solid element”.

Three-point Bending Model

A graphic representation of the geometry of a typical Finite Element model for the problem (high-low-high foam configuration) is presented in Fig. 1. In this case, the total number of elements for the 3D model is 56700 (16200 for each skin panel and 24300 for the core). Other mesh densities were examined as well, in order to show the effect they have on the results, especially on the post-yielding region.

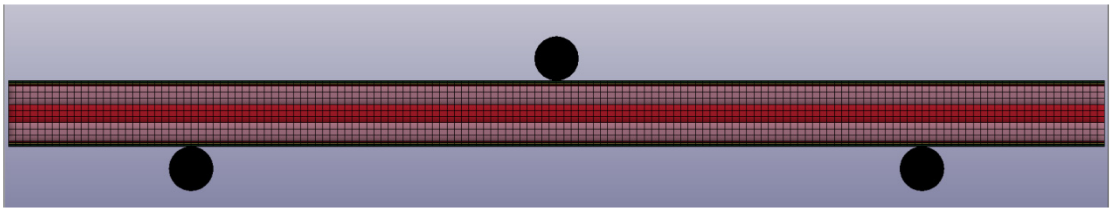

Fig. 1: Side view of the 3D model used for the three-point bending simulation of the high-low-high core configuration.

5. RESULTS

From our analysis the load-displacement curves extracted by the simulation are compared to the experimental ones. It is noted that in the work of Kaboglu et. al. [5] shear stress-displacement curves are given, which are transformed to load-displacement curves for direct comparison with the LS-DYNA results. For example, Fig. 2 shows the currently achieved correlation between the experimental and simulation results for the high-low-high core configuration, using the MAT_HONEYCOMB material. Linear results from another solver, the static of ANSYS© have been added for validity. The simulations have been performed for the first 20 mm of vertical displacement of the indentor, where no failure has appeared yet.

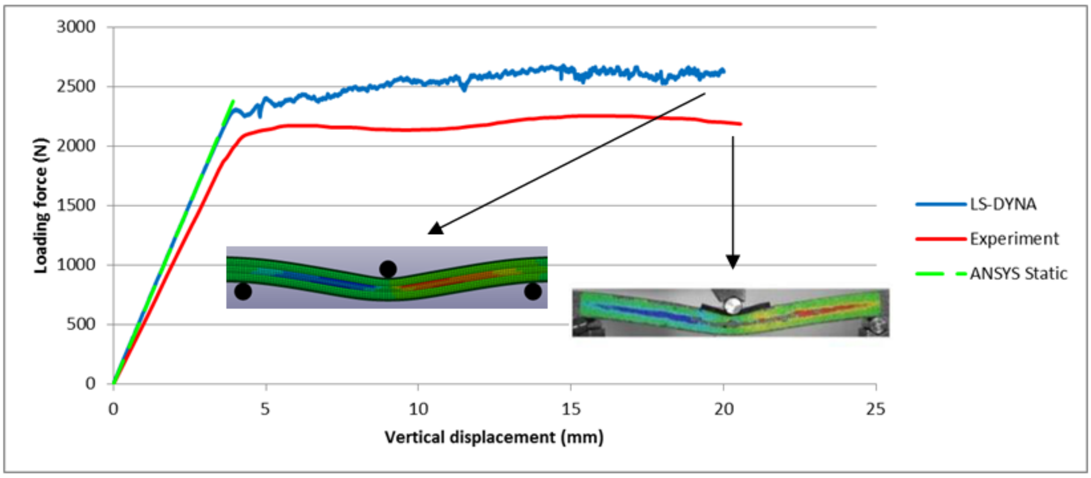

Fig. 2: Comparison of the load-displacement curves of the experiments and the simulations for the high-low-high core configuration. A linear curve from the static solver of ANSYS is included for comparison as well. The shapes of the beam at the 20 mm displacement are also added.

6. INVESTIGATIONS IN PROGRESS

As it was earlier stated, not all the desired results have been obtained yet. The two main directions in which our efforts are currently focused are the following ones:

- Modeling the catastrophic failure in the specimens under consideration. In the experimental procedure, catastrophic phenomena in either the skin (skin rupture) or the core (core shear cracking) were observed, based on the core configuration used. This process is simulated in LS-DYNA by using the MAT_ADD_EROSION option provided, which practically is a virtual tool to remove elements that fulfill a certain criterion. Such criteria are the maximum principal strain criterion, the maximum shear strain criterion, the maximum principal stress criterion etc. However, there is practically no straightforward way to determine which criterion is more preferable than others, as well as which value should be used as the critical one. Besides, and depending on the constitutive material model selected, the removal of elements may be highly dependent on the level of meshing used. Common practice in the literature is the calibration of the MAT_ADD_EROSION option according to the experimental results available [8, 9]. The failure criterion is selected by the catastrophic failure mode it produces, and the critical value is iteratively calibrated in order to “fit” the experimental results. This method is followed in the present work as well.
- After examining the level of applicability of the LS-DYNA material models under consideration, effort will be given in the extension of the simulations in a variety of specimens, by examining the effect that the core gradation combined with the specimen overall dimensions has in the bending response. However, the applicability of the MAT_ADD_EROSION option in this case is questionable. As it was stated above, it is a tool that is commonly calibrated according to experimental results available, and is difficult to be used “a priori” to accurately predict the catastrophic failure behavior. As a result, it is probable that the analysis will be limited to the prediction of the initial yield/failure phenomena and not the catastrophic ones.

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